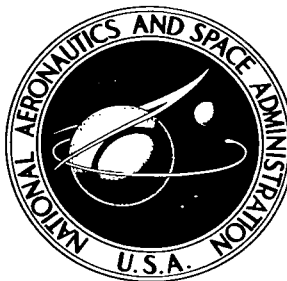


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EFFECTS OF WING DIHEDRAL AND PLANFORM
ON STABILITY CHARACTERISTICS
OF A RESEARCH MODEL AT
MACH NUMBERS FROM 1.80 TO 4.63

by Maurice O. Feryn and James F. Campbell

Langley Research Center

Langley Station, Hampton, Va.



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SUMMARY

An investigation has been made to determine the effects of wing geometric dihedral and planform on the stability characteristics of a wing-body-tail research model. Geometric dihedral angles were set at 3° , 0° , and -3° for the 31° and 73° swept-leading-edge wings investigated. Tests were performed at angles of attack from about -4° to 24° , at angles of sideslip from about -4° to 8° , at Mach numbers from 1.80 to 4.63, and at a Reynolds number per foot of 3.0×10^6 .

The directional stability was increased by positive geometric dihedral and decreased by negative geometric dihedral for both the tail-on and tail-off configurations, particularly at the high angles of attack and high Mach numbers as a result of dynamic-pressure effects induced on the fuselage afterbody. Positive effective dihedral was increased by positive geometric dihedral and decreased by negative geometric dihedral. The highly swept wing with subsonic leading edges provided larger negative values of effective dihedral than did the wing with lower sweep and supersonic leading edges. The amount of geometric dihedral used in these tests had little or no effect on the aerodynamic characteristics in pitch.

INTRODUCTION

A large research effort is now being made on aircraft such as the multi-mission fighter, the supersonic transport, and vehicles of even higher Mach number which are capable of flight into the hypersonic speed region. Because of the inherent loss of lift on stabilizing surfaces with increased Mach number, the stability characteristics of these aircraft are becoming a serious problem not only in cruise-flight conditions but also in maneuvering conditions at higher angles of attack. Some of the factors affecting the stability of aircraft at supersonic speeds have been discussed in references 1 to 5. Although considerable data have been obtained concerning the effects of two of these

factors (geometric dihedral and wing planform) on the aerodynamic characteristics in pitch and sideslip at low Mach numbers (refs. 6, 7, and 8, for example), only a small amount of information is available at the higher supersonic Mach numbers (ref. 9, for example).

An investigation has been made on a wing-body-tail model to determine the effects of geometric dihedral and wing planform on the stability characteristics of aircraft at high supersonic Mach numbers, and the test results are presented herein. The model was tested with and without a vertical tail and with two wing planforms - a swept wing with 73° of leading-edge sweep and a trapezoidal wing with 31° of leading-edge sweep. The tests were performed in the Langley Unitary Plan wind tunnel at Mach numbers from 1.80 to 4.63, at angles of attack from about -4° to 24° , and at angles of sideslip from about -4° to 8° . The Reynolds number per foot for these tests was 3.0×10^6 .

SYMBOLS

The lateral force and moment data are referred to the body-axis system, and the longitudinal force and moment data are referred to the stability-axis system. The reference moment center was located 17.15 inches behind the nose of the fuselage on the body center line. The data were reduced with the use of the geometric dimensions of the swept wing.

The symbols used are defined as follows:

b	wing span, ft
c	section chord, ft
\bar{c}	mean geometric chord, ft
C_D	drag coefficient, $\frac{\text{Drag}}{qS_w}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS_w}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_w \bar{c}}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS_w b}$
$C_{l\beta}$	effective-dihedral parameter, $\frac{\Delta C_l}{\Delta \beta}$, per deg

$$C_{l_{\beta\alpha}} = \frac{\Delta C_l / \Delta \beta}{\Delta \alpha}$$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS_w b}$

$C_{n\beta}$ directional-stability parameter, $\frac{\Delta C_n}{\Delta \beta}$, per deg

C_Y side-force coefficient, $\frac{\text{Side force}}{qS_w}$

$C_{Y\beta}$ side-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$, per deg

L/D lift-drag ratio, $\frac{C_L}{C_D}$

M Mach number

q free-stream dynamic pressure, lb/sq ft

S_w reference wing area, 1.19 sq ft

α angle of attack, deg

β angle of sideslip, deg

Γ wing geometric dihedral angle, deg

APPARATUS AND TESTS

Model

Drawings of the research model are presented in figure 1. The investigation was conducted on an ogive-nose cylindrical body in conjunction with trapezoidal- and swept-planform wings and a vertical tail; no horizontal tail was used on the model. The trapezoidal-planform wing had 31° leading-edge sweep, a 4-percent-thick circular-arc airfoil section in the streamwise direction, a planform area of 1.33 square feet, and an aspect ratio of 3.007. The swept wing had 73° leading-edge sweep, an NACA 65A004 airfoil section in the streamwise direction, a planform area of 1.19 square feet, and an aspect ratio of 1.313. The geometric dihedral for each wing could be set at angles of 3° , 0° , and -3° .

The cylindrical portion of the circular body was constructed of wood and fiber glass with a steel core, and the nose was made of stainless steel.

Tunnel

Tests were conducted in both the low and high Mach number test sections of the Langley Unitary Plan wind tunnel, which is a variable-pressure continuous-flow tunnel. Each test section is approximately 4 feet square and 7 feet long. The nozzles leading to the test sections are the asymmetric sliding-block type that permit a continuous variation in Mach number from about 1.5 to 2.9 in the low Mach number test section and from about 2.3 to 4.7 in the high Mach number test section.

Test Conditions

The stagnation temperatures and pressures for the various test Mach numbers are as follows:

Mach number	Stagnation temperature, °F	Stagnation pressure, psia
1.80	150	12.65
2.16	150	14.86
2.50	150	17.62
2.86	150	21.41
3.95	175	40.00
4.63	175	54.74

The Reynolds number per foot was constant at 3.0×10^6 for all tests. The stagnation dewpoint was maintained at -30° F in order to avoid condensation effects.

The configurations were tested through an angle-of-attack range from about -4° to 24° and through an angle-of-sideslip range from about -4° to 8° . Data for the configuration with and without the vertical tail were obtained for both wing planforms at geometric-dihedral angles of 3° , 0° , and -3° .

In order to obtain turbulent flow over the model, transition strips composed of No. 60 carborundum grains set in a plastic adhesive were used on all configurations. These strips were 1/16 inch wide and were placed 1/2 inch from the nose on the cylindrical body and 1/2 inch from the leading edge in a streamwise direction on the wing and tail surfaces.

Measurements

Aerodynamic forces and moments were measured by means of a six-component electrical strain-gage balance housed within the model. The balance was rigidly fastened to a sting support which was in turn attached to the tunnel support system. The balance-chamber pressure was measured by means of a single static-pressure orifice located in the balance cavity.

Accuracy

The accuracy of the individual measured quantities, based on calibrations and repeatability of data, is estimated to be within the following limits:

C_D	± 0.0002
C_L	± 0.002
C_l	± 0.001
C_m	± 0.0004
C_n	± 0.0004
C_Y	± 0.002
α , deg	± 0.10
β , deg	± 0.10
$M = 1.80$ to 2.86	± 0.015
$M = 3.95$ and 4.63	± 0.050

Corrections

Angles of attack were corrected for tunnel-flow angularity, and angles of attack and sideslip were corrected for deflection of the balance and sting support due to aerodynamic loads. The drag data were adjusted to correspond to free-stream static conditions at the base of the model.

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

Typical aerodynamic characteristics in sideslip:

Trapezoidal-wing configuration, tail on	2
Swept-wing configuration	3

Effect of geometric dihedral on sideslip parameters:

Trapezoidal-wing configuration, tail off	4
Trapezoidal-wing configuration, tail on	5
Swept-wing configuration, tail off	6
Swept-wing configuration, tail on	7

Effect of wing planform and Mach number on the variation of the slope of the lateral-stability parameter with angle of attack 8

Effect of geometric dihedral on aerodynamic characteristics in pitch:

Trapezoidal-wing configuration, tail on	9
Swept-wing configuration, tail on	10

DISCUSSION

Sideslip Characteristics

Typical aerodynamic characteristics in sideslip at the higher angles of attack are presented in figures 2 and 3 for the trapezoidal- and swept-wing configurations, respectively. These figures are presented primarily to show the linearity of the data since all sideslip parameters presented herein were obtained from incremental results of tests made throughout the angle-of-attack range at sideslip angles of about 0° and 4° . The results with the exception of some of the C_n data for the swept-wing configuration (fig. 3(a), for example) are relatively linear for sideslip angles up to 4° . It is believed, however, that even though the $C_{n\beta}$ values presented in this paper for the swept-wing configuration at the higher angles of attack may not be quantitatively exact, the comparisons shown are valid.

The effects of wing geometric dihedral on the sideslip parameters for the trapezoidal-wing configuration are shown in figures 4 and 5 for the vertical tail off and on, respectively. For the tail-off condition, positive geometric dihedral tends to increase the directional stability, whereas negative geometric dihedral tends to decrease the directional stability as the angle of attack increases. This effect becomes increasingly significant with increase in Mach number, particularly at the higher angles of attack. The variations in $C_{n\beta}$ with geometric dihedral angle at the higher angles of attack are associated with the change in dynamic pressure over the rear of the model caused by incremental changes of wing lift due to the lateral component of flow in sideslip (ref. 10). This effect is such that positive dihedral provides a local increase in lift for the windward wing with an attendant stabilizing increase in dynamic pressure over the afterbody. Negative dihedral provides an opposite effect.

Increasing the geometric dihedral from -3° to 3° leads to an almost linear increase in positive effective dihedral at all test angles of attack and Mach numbers. There is, however, a decrease in the ability of geometric dihedral to produce effective dihedral with increasing Mach number at low angles of attack.

With the vertical tail on, the trapezoidal-wing configuration generally displays small changes in directional stability with wing dihedral at the lower angles of attack. However, at the higher test angles of attack the results are similar to those for the configuration with the tail off in that positive geometric dihedral of the wing produces the greatest directional stability and negative geometric dihedral produces the least. There is little or no difference in the effect of geometric dihedral on $C_{l\beta}$ for the configuration with or without the vertical tail, although it may be noted that at the higher Mach numbers the effective dihedral varies only slightly with angle of attack for the tail-on case.

The effects of geometric dihedral on the sideslip parameters of the swept-wing configuration are shown in figures 6 and 7 for the vertical tail off and on, respectively. The effects of geometric dihedral on $C_{n\beta}$ for the

swept-wing configuration are about the same as those previously discussed for the trapezoidal-wing configuration. As noted in the data of figure 7 for the swept-wing configuration, the large decrease in directional stability with angle of attack at the lower test Mach numbers is offset at the higher Mach numbers by the increased dynamic pressure induced by the wing on the afterbody. Thus, in spite of the decrease in $C_{n\beta}$ at low angles of attack, the configuration maintains positive directional stability throughout the angle-of-attack range. In the test Mach number range planform does not greatly affect the directional stability of the configuration.

Geometric dihedral of the swept wing produces effects on $C_{l\beta}$ similar to those already noted for the trapezoidal-wing configuration, although to a considerably lesser degree. The $C_{l\beta}$ variation with α is considerably more negative at low angles of attack for the swept wing (fig. 6) than for the trapezoidal wing (fig. 4), particularly at the lower Mach numbers. To illustrate this fact more effectively, the slope $C_{l\beta\alpha}$ is shown in figure 8 as a function of Mach number for both wing planforms. This figure indicates that $C_{l\beta\alpha}$ is much smaller in absolute value for the trapezoidal-wing configuration than for the swept-wing configuration, and has only a small decrease (becoming less negative) over the Mach number range. The swept-wing configuration has relatively large negative values of $C_{l\beta\alpha}$ at the lower Mach numbers but these values decrease rapidly up to a Mach number of about 3.40 and then show little change with further increase in Mach number. This effect of wing planform on $C_{l\beta\alpha}$ may be explained by the differences in the wing-panel lift-curve slope for the two wings. The trapezoidal wing has a leading-edge sweep of 31° so that large portions of the wing are supersonic at all test Mach numbers (leading edge swept ahead of Mach lines). When this configuration is sideslipped, the local Mach number increases for the windward wing and decreases for the leeward wing. Since the lift-curve slope of a wing decreases with increase in supersonic Mach number, the windward wing loses lift, and the leeward wing gains lift; thus, less negative values of $C_{l\beta\alpha}$ are attained. The swept wing, on the other hand, has a leading-edge sweep of 73° and the entire wing is subsonic at Mach numbers up to about 3.40, and large portions are subsonic even up to the highest test Mach number. Thus, the windward wing in sideslip for this configuration would have an increase in lift-curve slope for its subsonic portion, whereas the leeward wing would have a decrease in lift-curve slope. This combination would lead to more negative values of $C_{l\beta\alpha}$ than for the trapezoidal-wing configuration. The decrease in $C_{l\beta\alpha}$ at the higher Mach numbers for the swept wing is caused by more of the windward wing becoming supersonic.

Longitudinal Characteristics

The effects of geometric dihedral on the aerodynamic characteristics in pitch are presented in figures 9 and 10 for the trapezoidal- and swept-wing configurations, respectively. These data show that the amount of geometric dihedral used for these tests has little or no effect on the pitch characteristics of the configurations. In addition, there are essentially no effects of planform on the linearity of the lift and pitching-moment curves with angle of attack, although, as expected, the lift-curve slope for the trapezoidal-wing configuration is somewhat greater than that for the swept-wing configuration.

CONCLUSIONS

An investigation made to determine the effects of wing geometric dihedral and planform on the stability characteristics of a wing-body-tail model at Mach numbers from 1.80 to 4.63 indicated the following conclusions:

1. The directional stability was increased by positive geometric dihedral and decreased by negative geometric dihedral for both the tail-on and tail-off configurations, particularly at the high angles of attack and Mach numbers as a result of dynamic-pressure effects induced on the fuselage afterbody.

2. Positive effective dihedral was increased by positive geometric dihedral and decreased by negative geometric dihedral.

3. The swept wing with the high sweep angle and the subsonic leading edges provided larger negative values of effective dihedral than did the trapezoidal wing with the lower sweep angle and the supersonic leading edges.

4. The amount of geometric dihedral used in the wing configurations of these tests had little or no effect on the aerodynamic characteristics in pitch.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 23, 1965.

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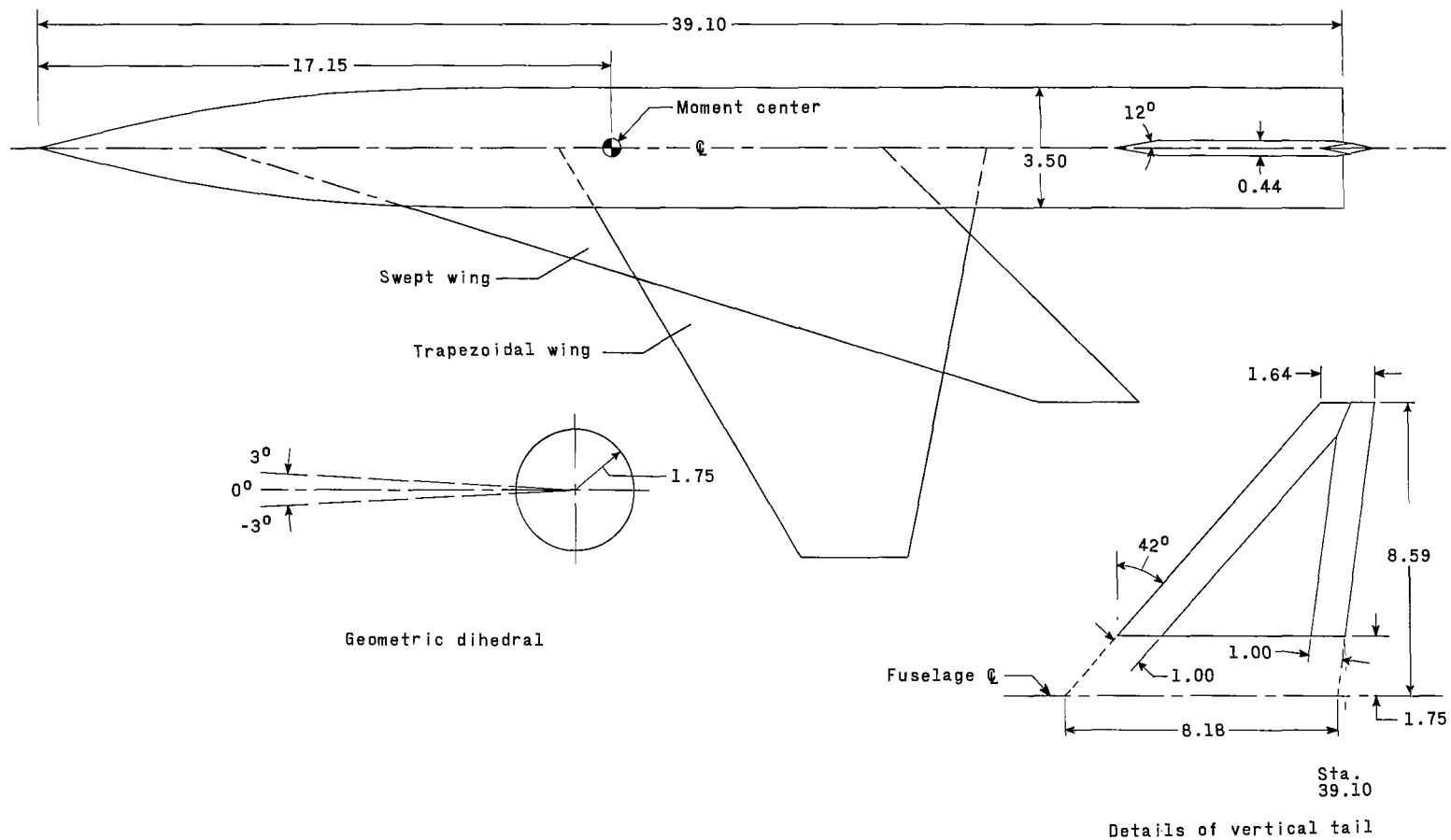
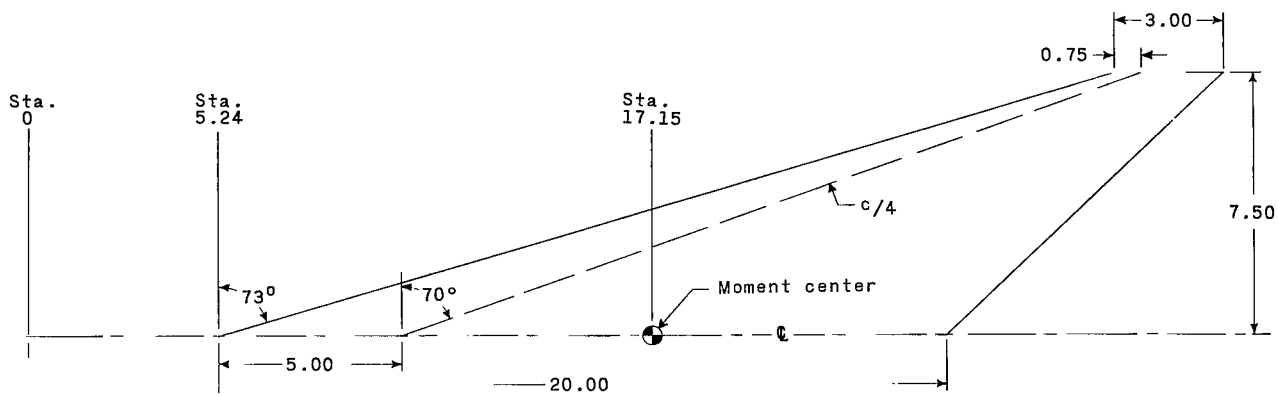
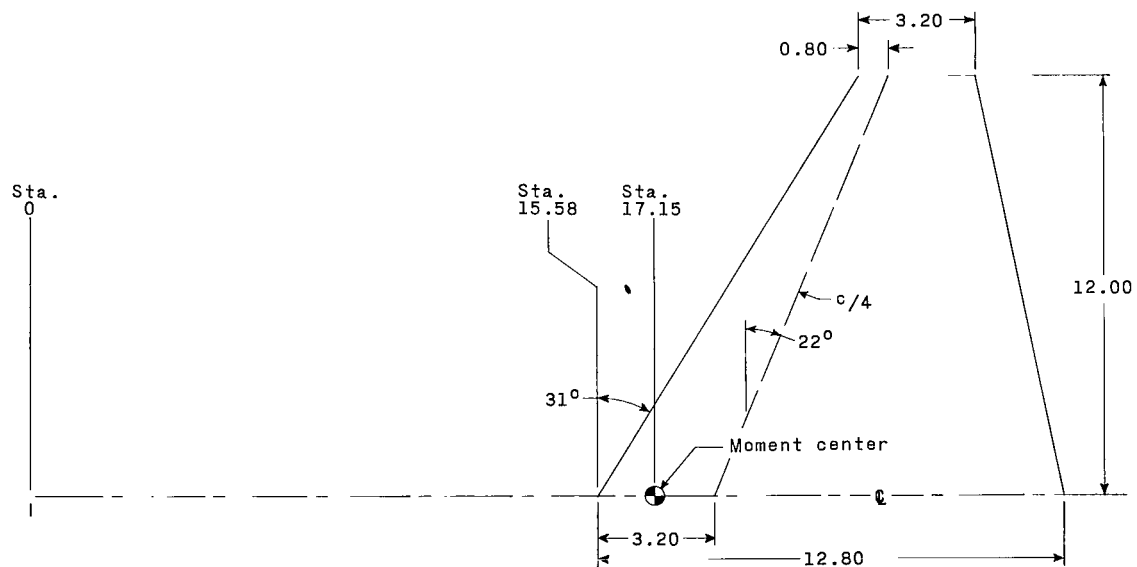


Figure 1.- Model drawing. (All dimensions in inches unless otherwise specified.)

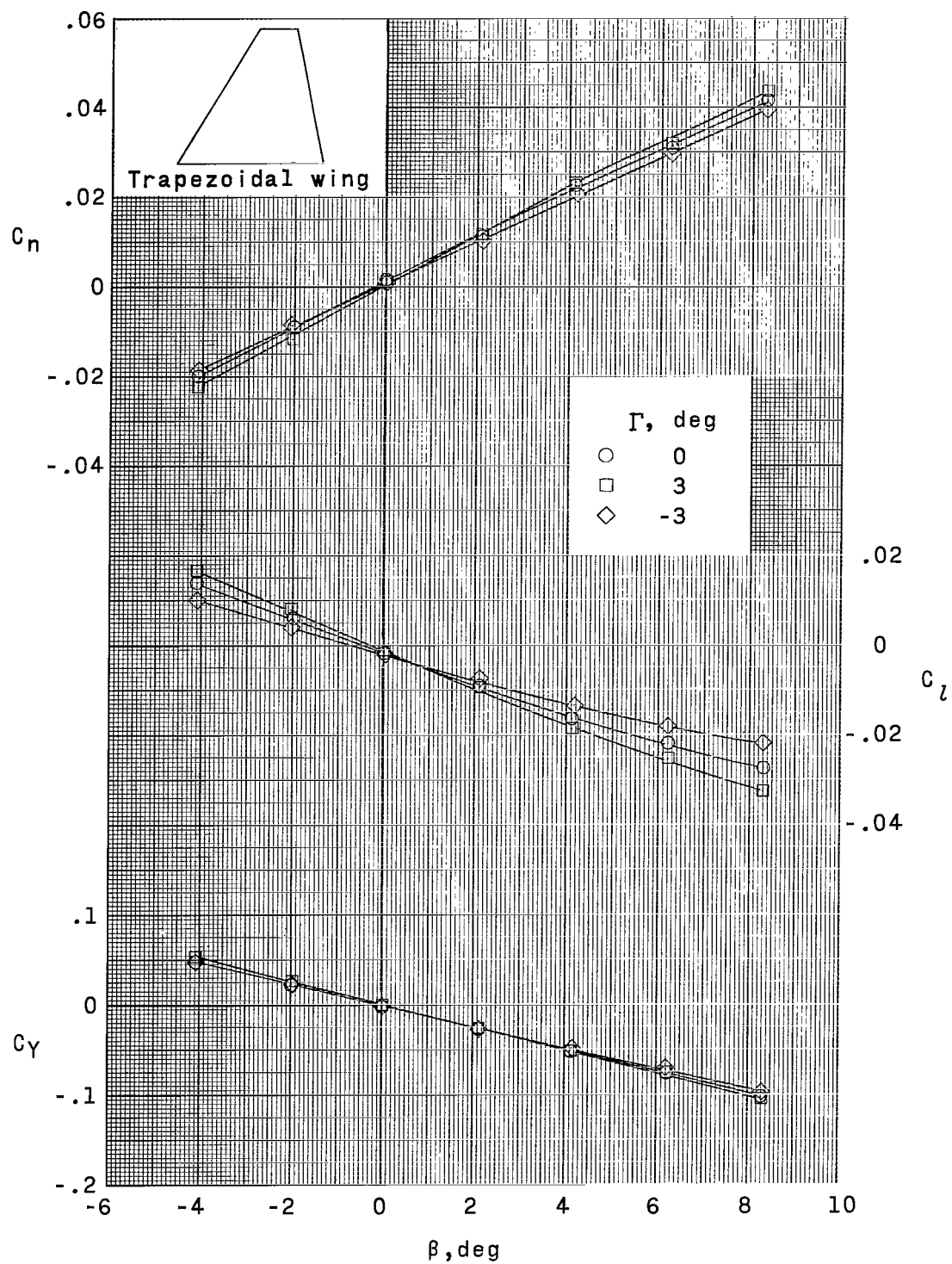


Swept wing



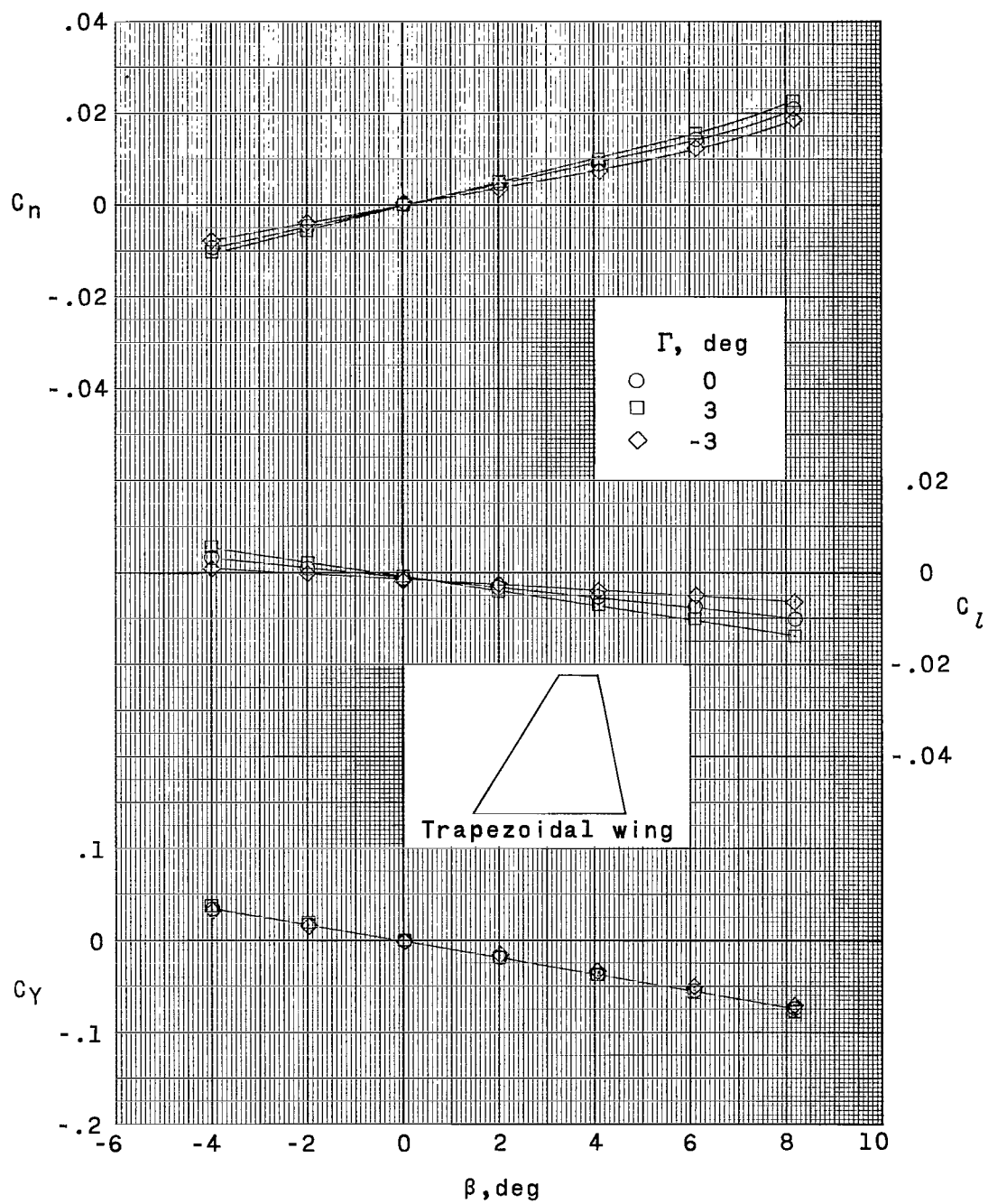
Trapezoidal wing

Figure 1.- Concluded.



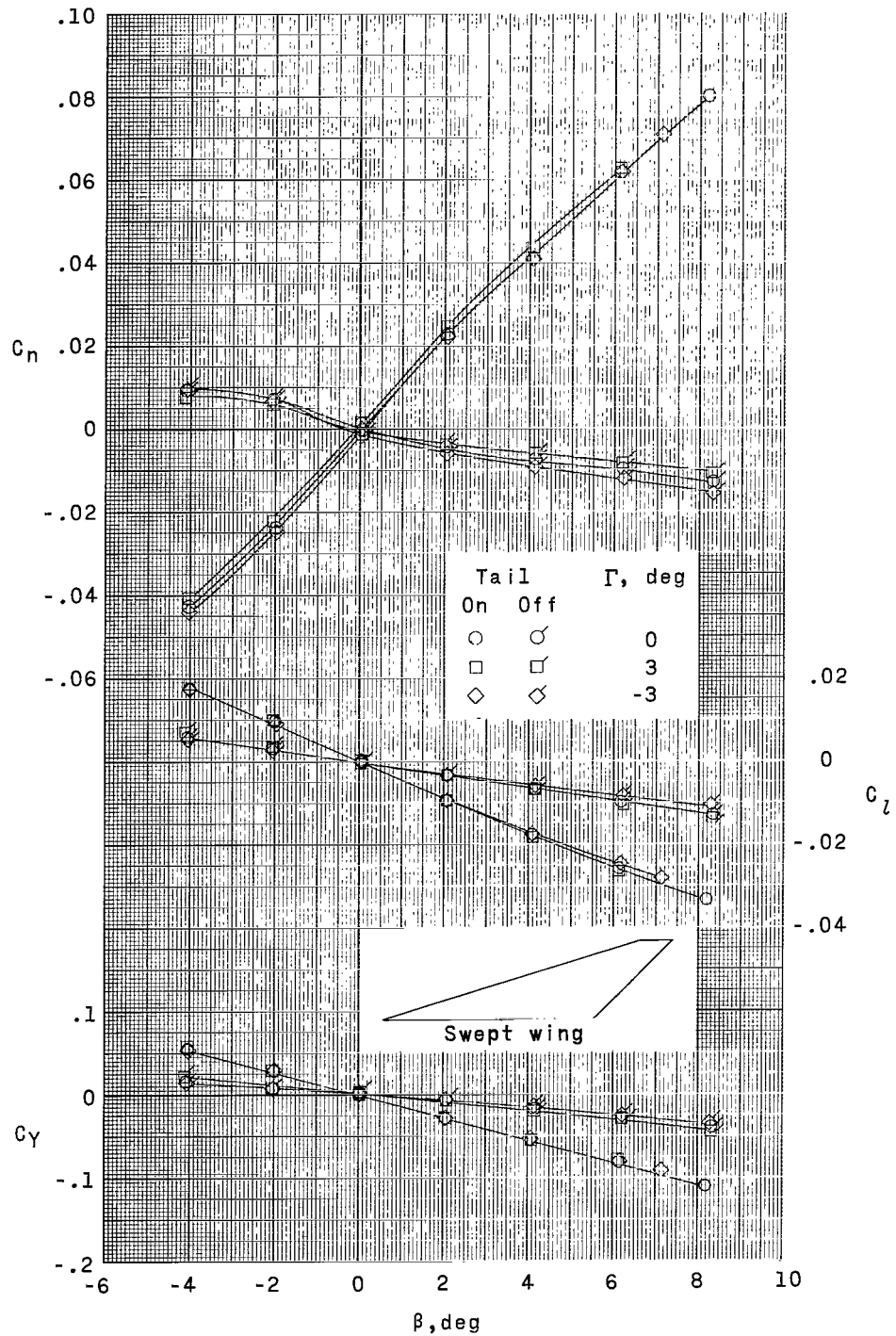
(a) $M = 2.50$; $\alpha \approx 17^\circ$.

Figure 2.- Typical aerodynamic characteristics in sideslip for trapezoidal-wing configuration. Tail on.



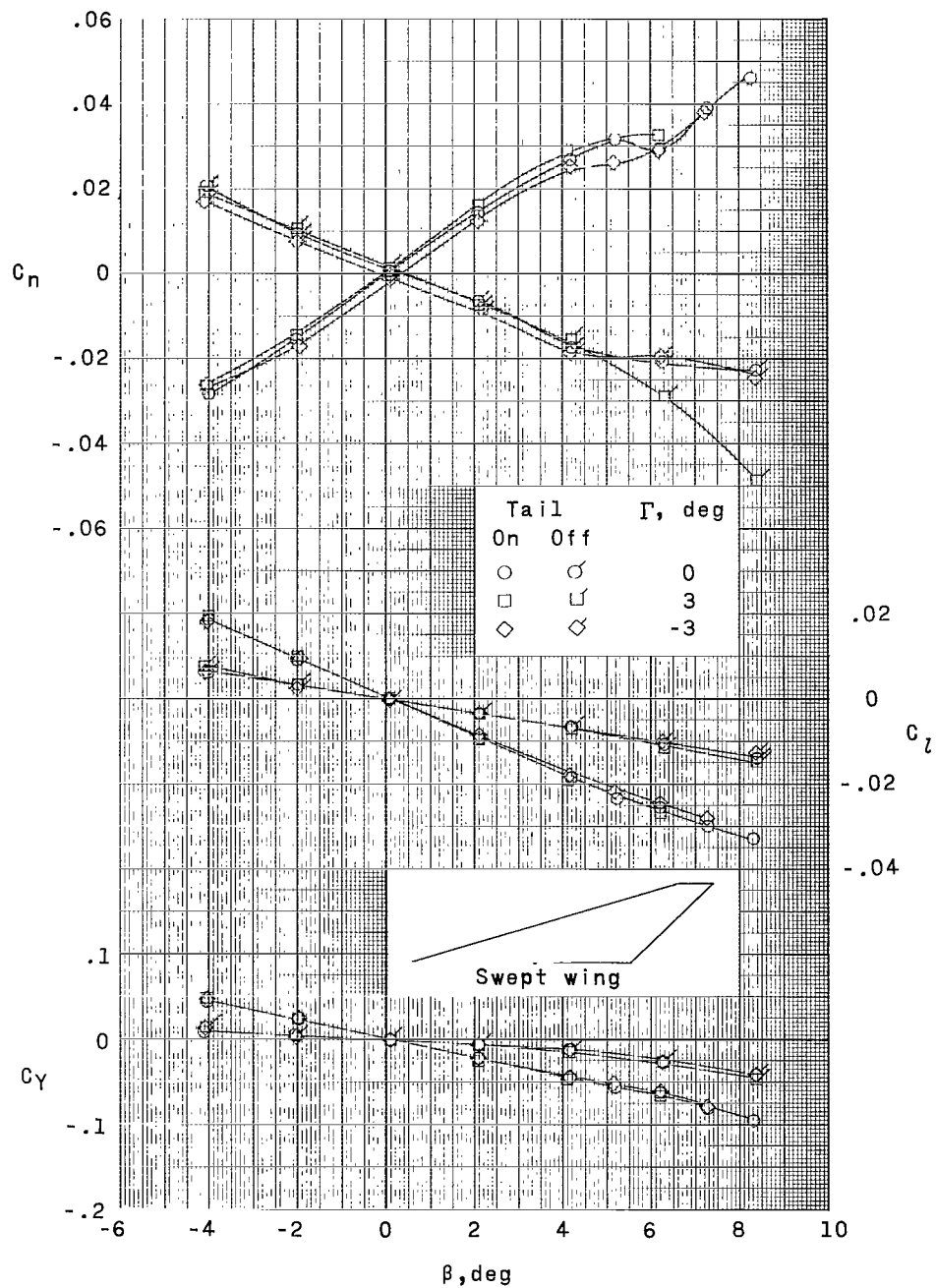
(b) $M = 4.63$; $\alpha \approx 17^\circ$.

Figure 2.- Concluded.



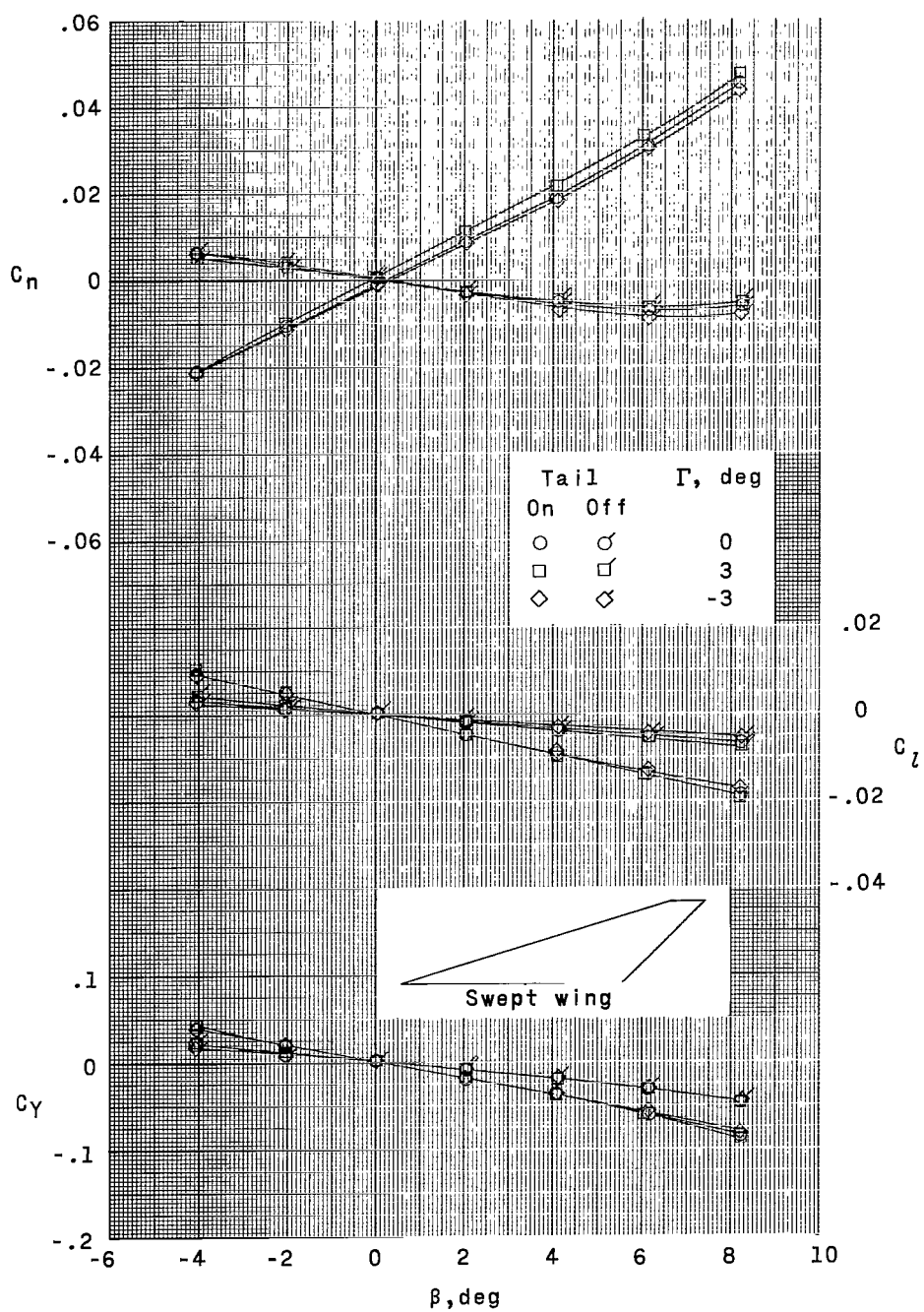
(a) $M = 1.80$; $\alpha \approx 12^\circ$.

Figure 3.- Typical aerodynamic characteristics in sideslip for swept-wing configuration.



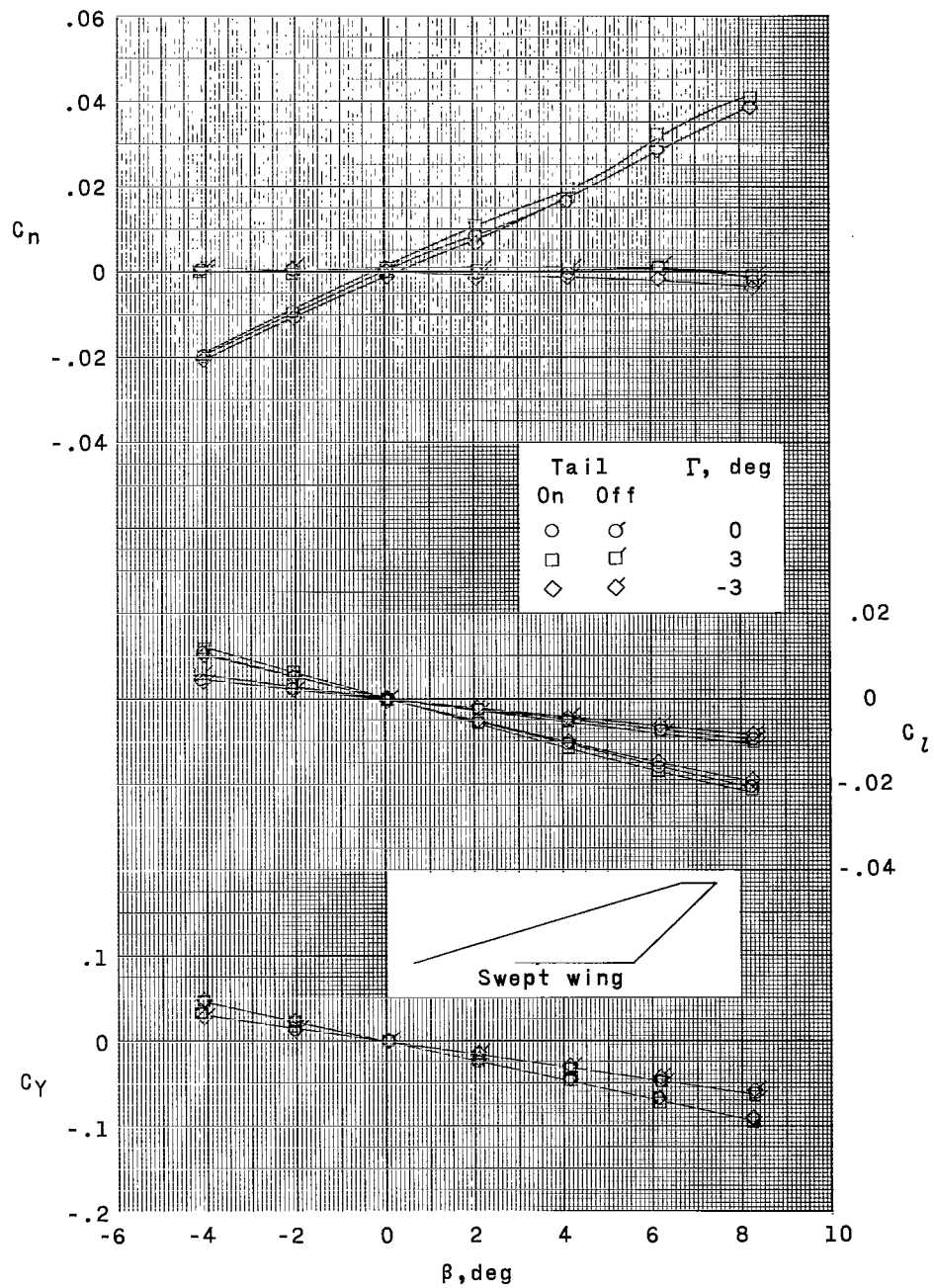
(b) $M = 1.80$; $\alpha \approx 17^\circ$.

Figure 3.- Continued.



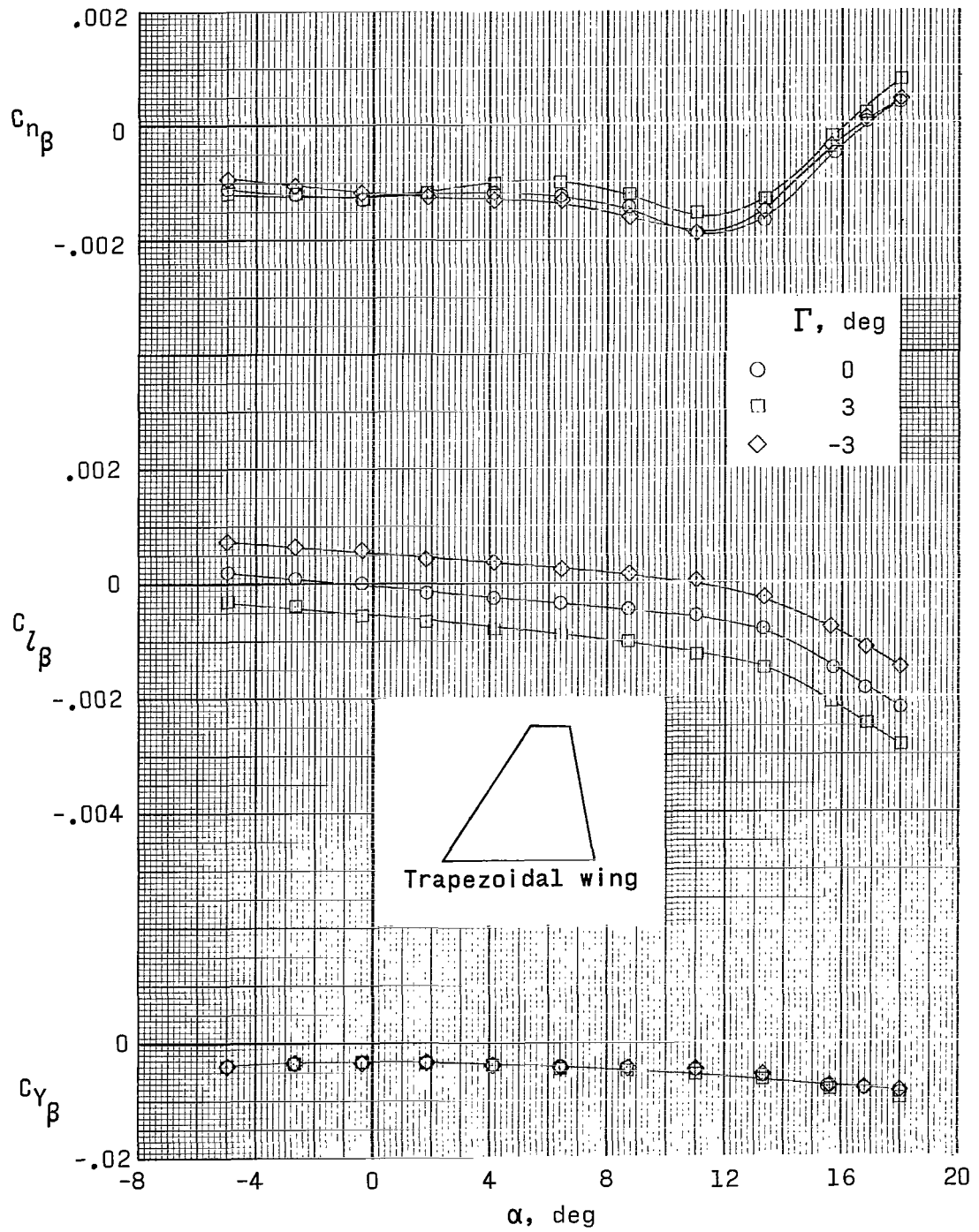
(c) $M = 2.86; \alpha \approx 12^\circ$.

Figure 3.- Continued.



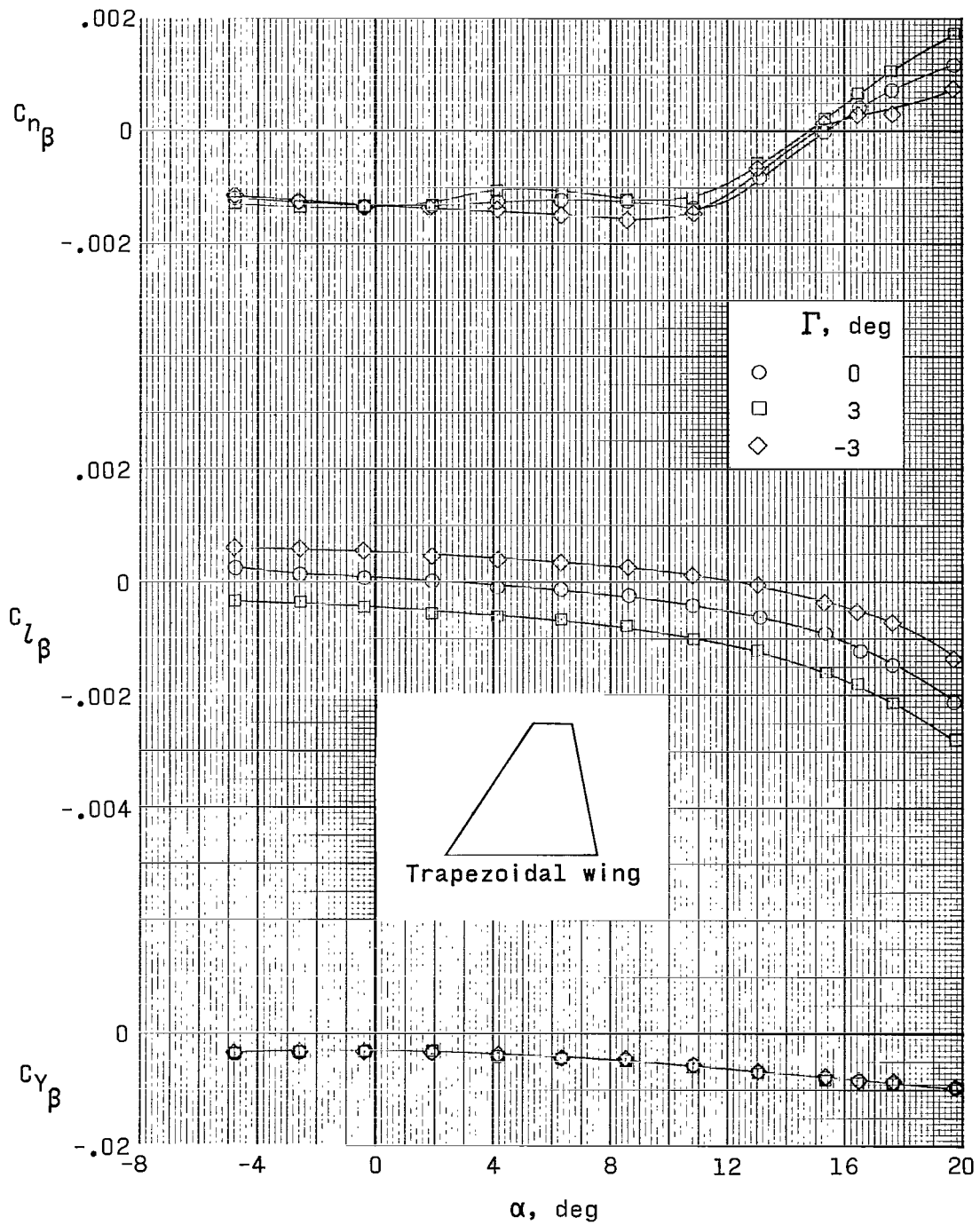
(d) $M = 2.86; \alpha \approx 17^\circ$.

Figure 3.- Concluded.



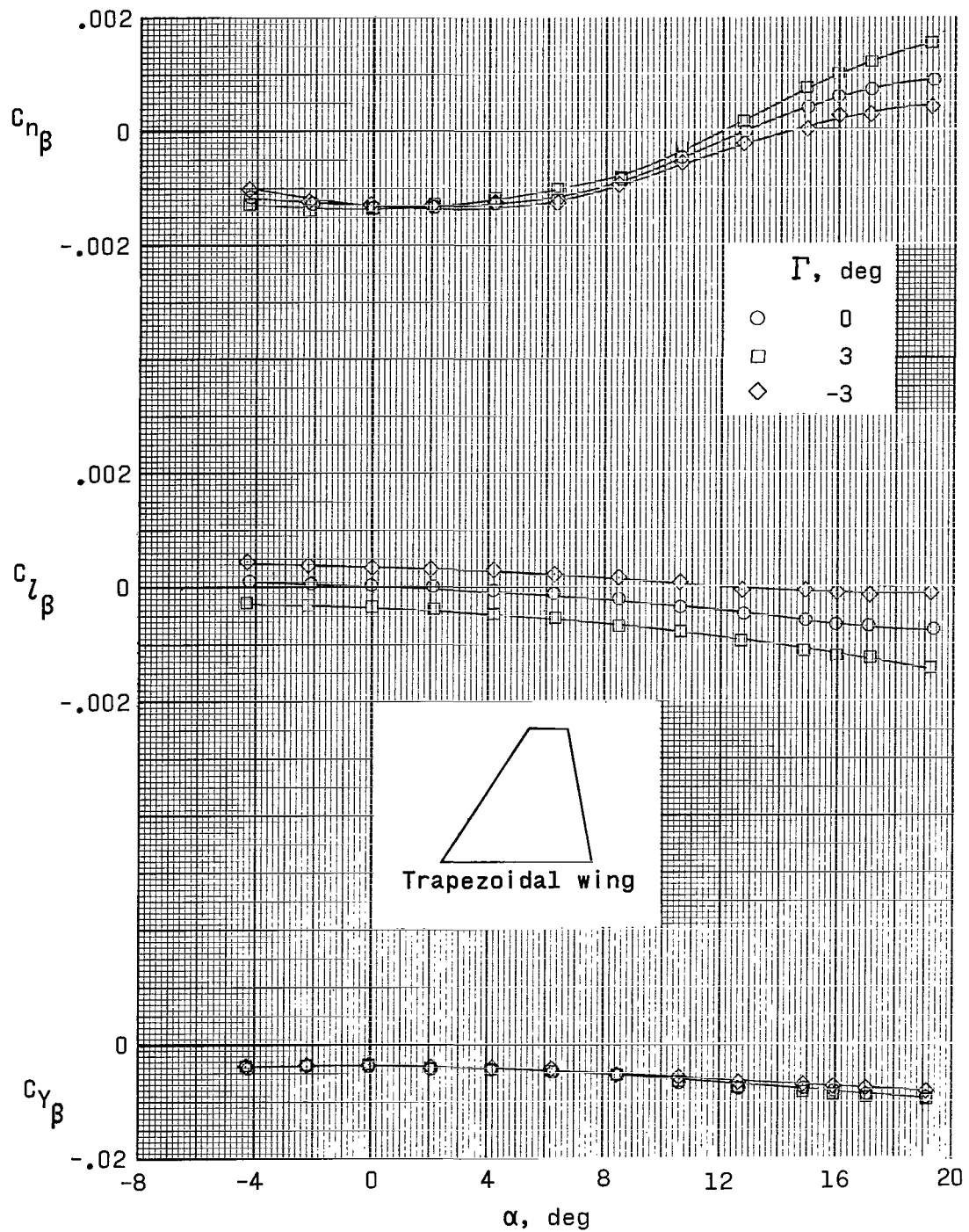
(a) $M = 2.50$.

Figure 4.- Effect of geometric dihedral on sideslip parameters for trapezoidal-wing configuration. Tail off.



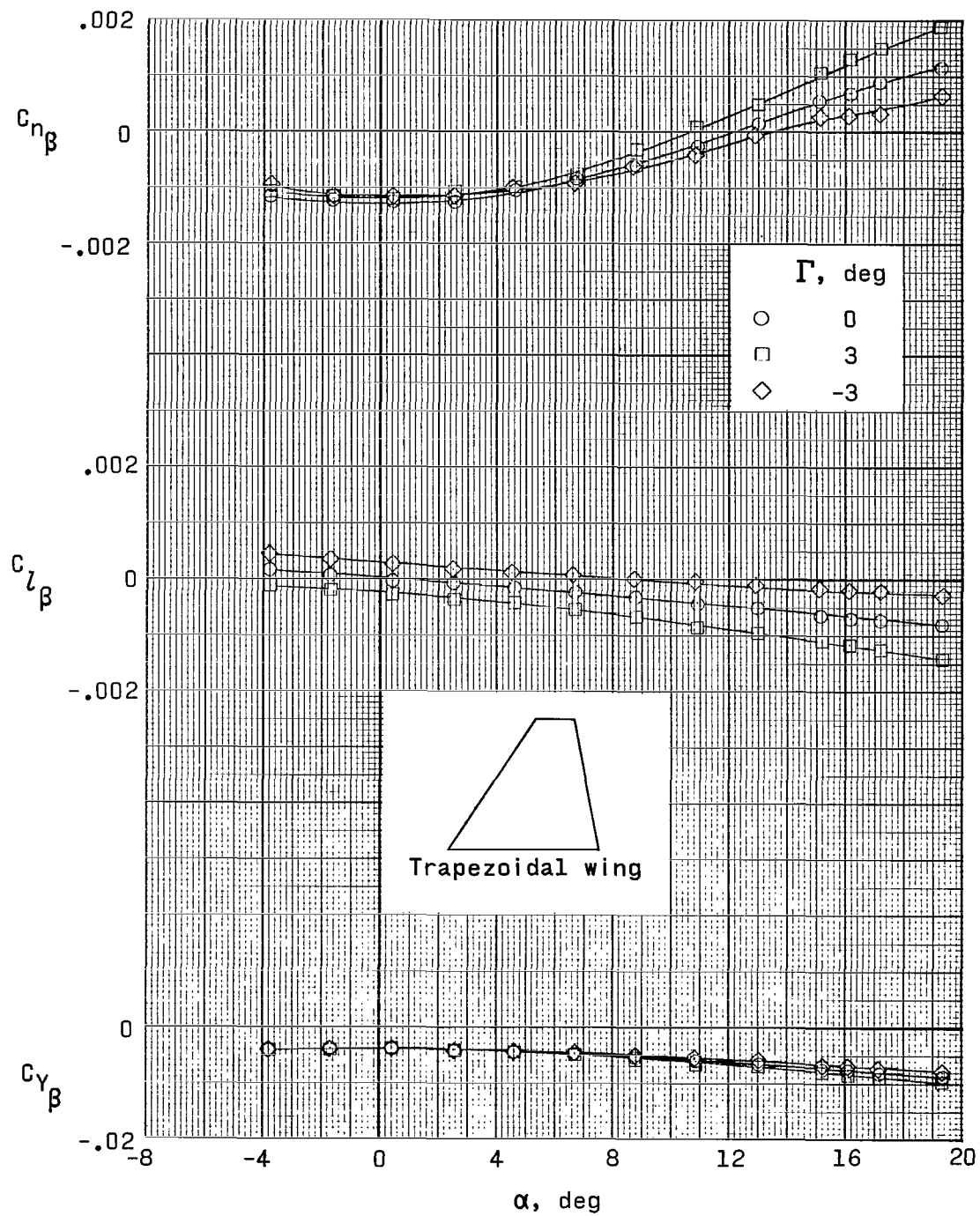
(b) $M = 2.86$.

Figure 4.- Continued.



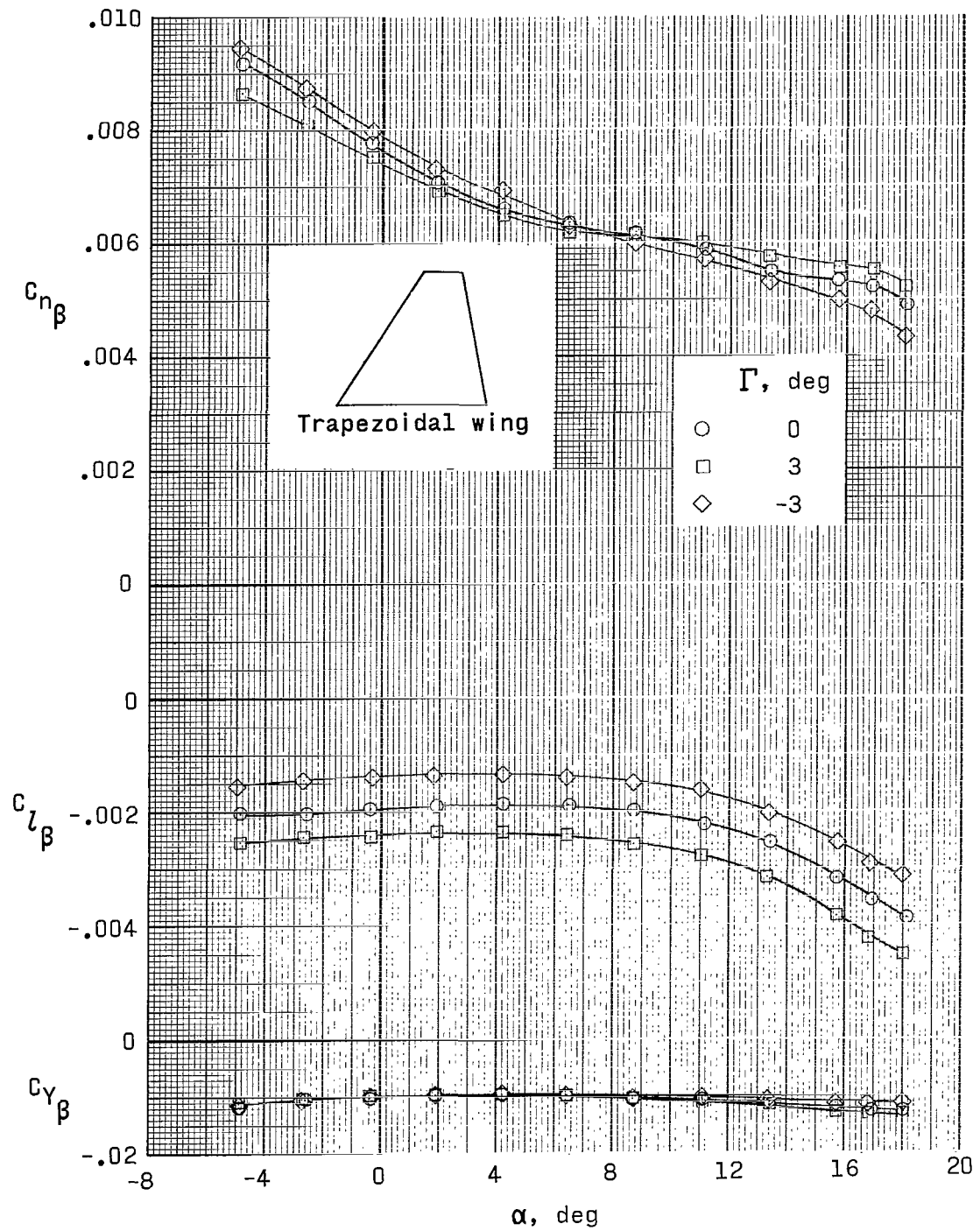
(c) $M = 3.95$.

Figure 4.- Continued.



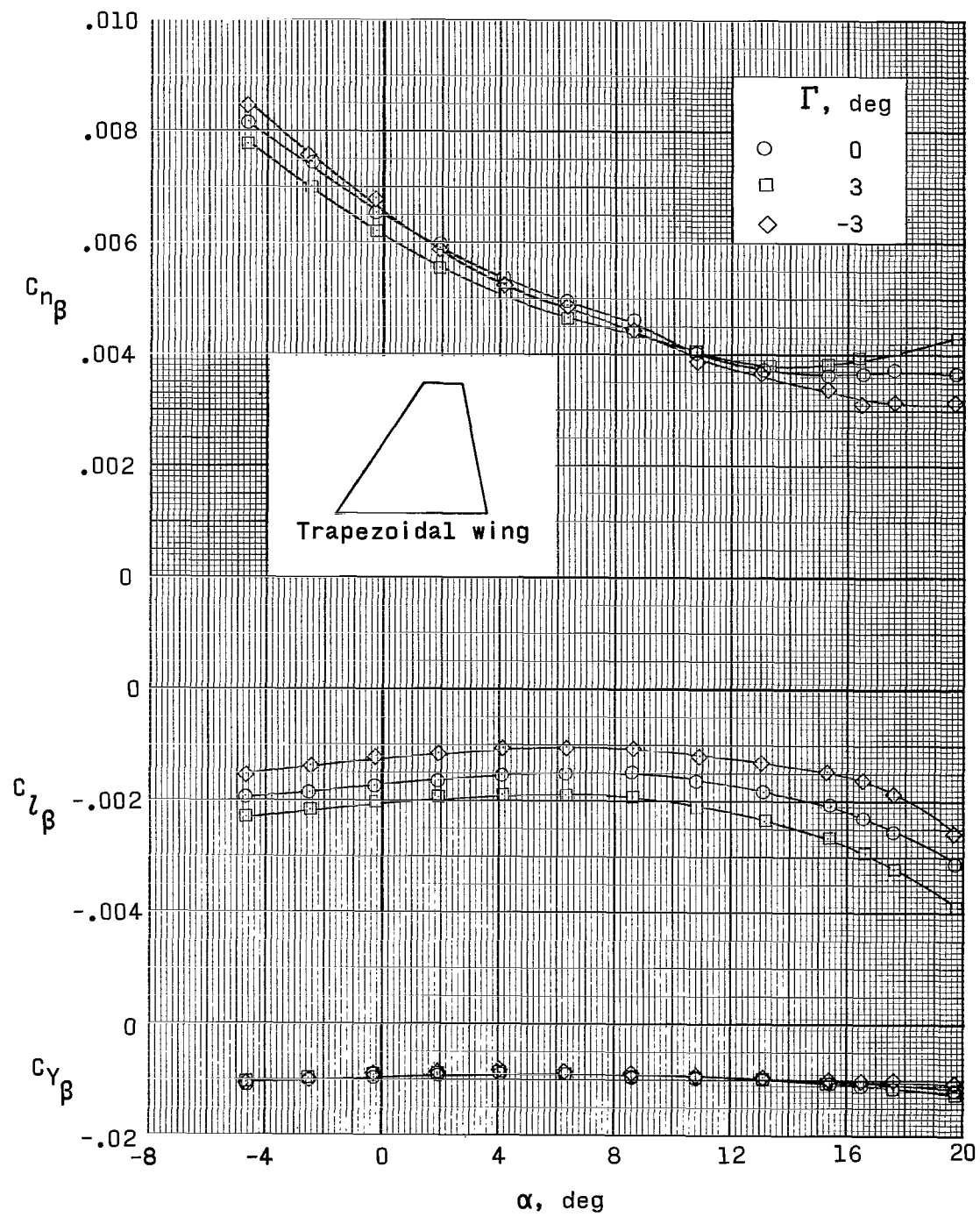
(d) $M = 4.63$.

Figure 4.- Concluded.



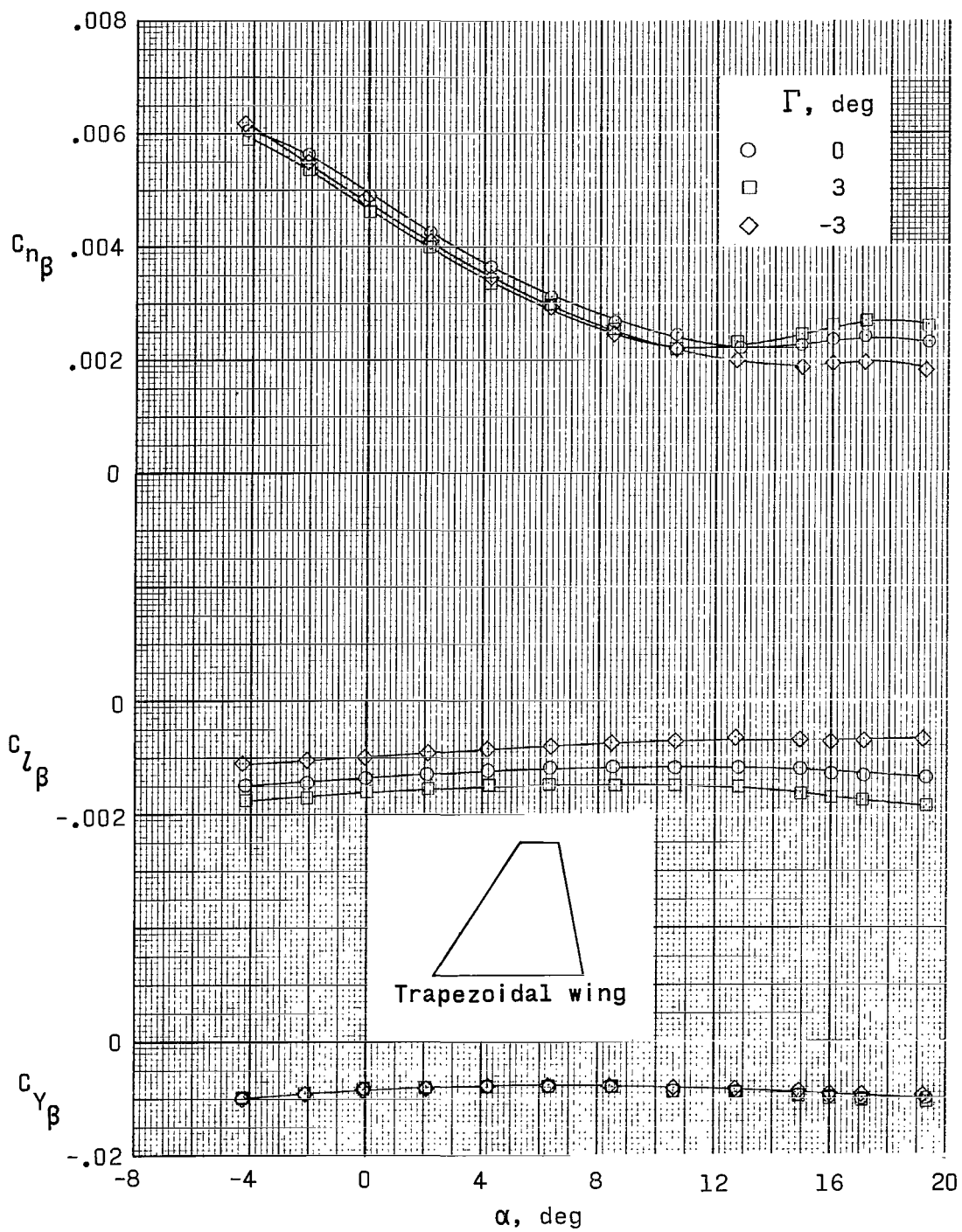
(a) $M = 2.50$.

Figure 5.- Effect of geometric dihedral on sideslip parameters for trapezoidal-wing configuration. Tail on.



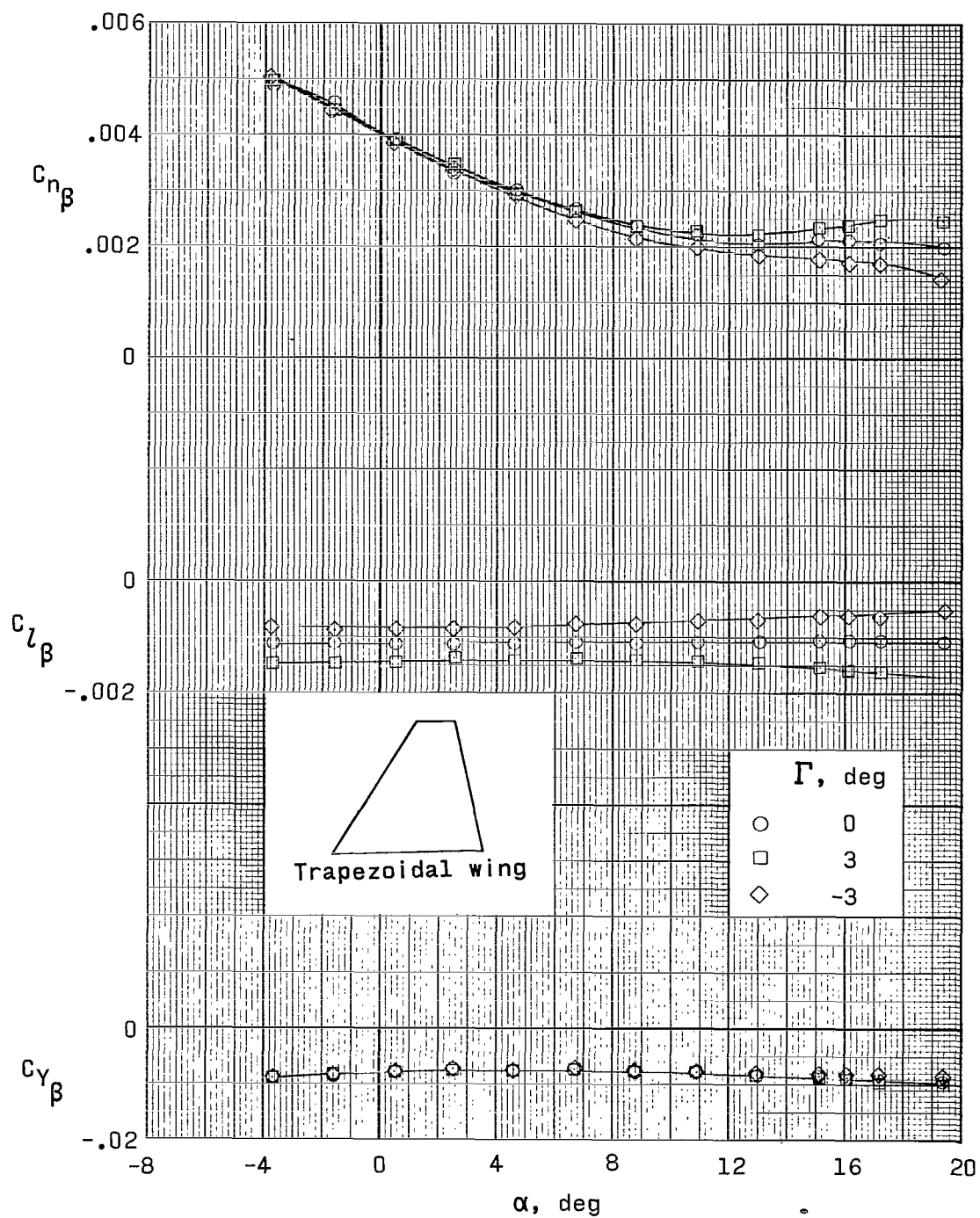
(b) $M = 2.86$.

Figure 5.- Continued.



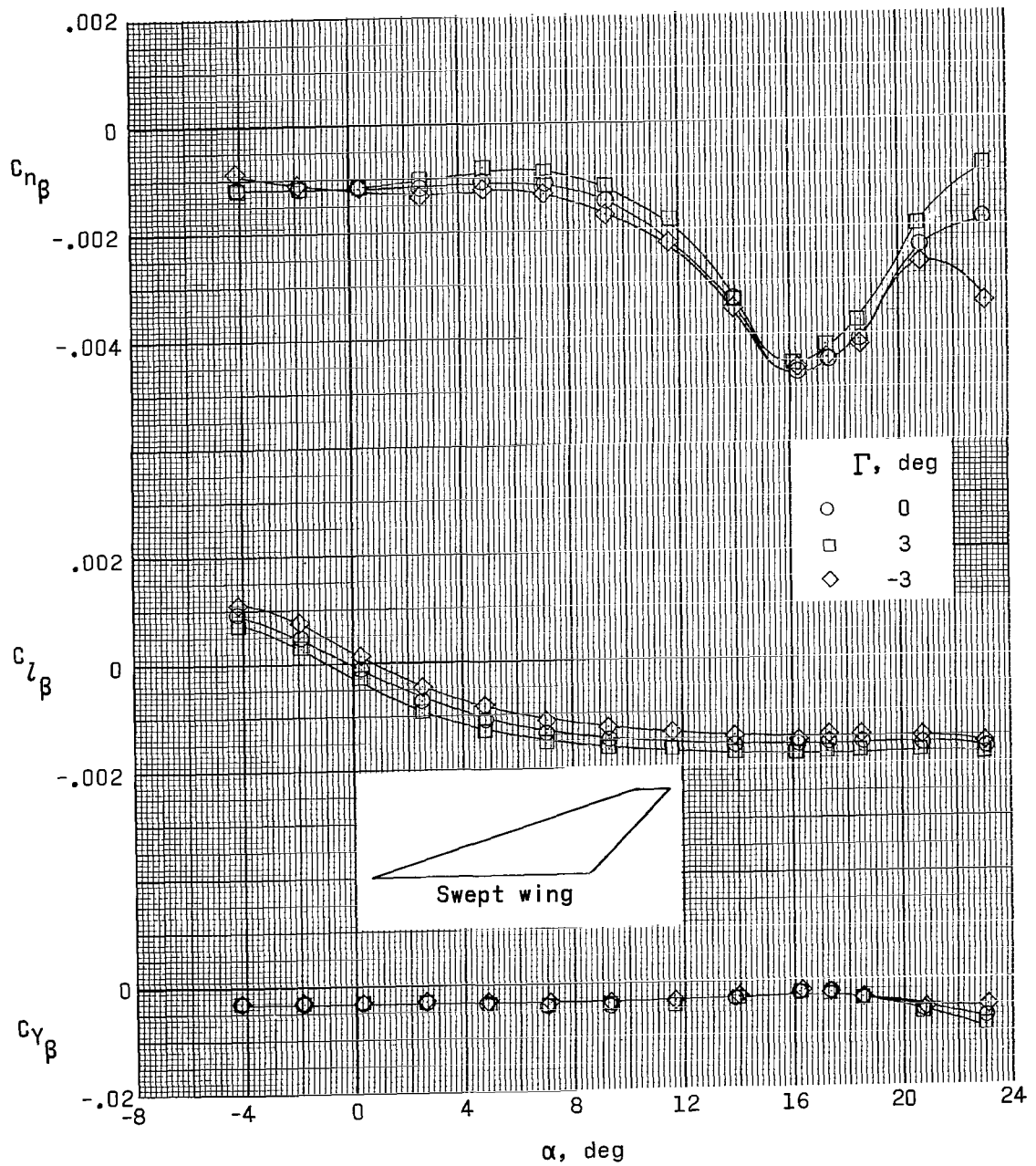
(c) $M = 3.95$.

Figure 5.- Continued.



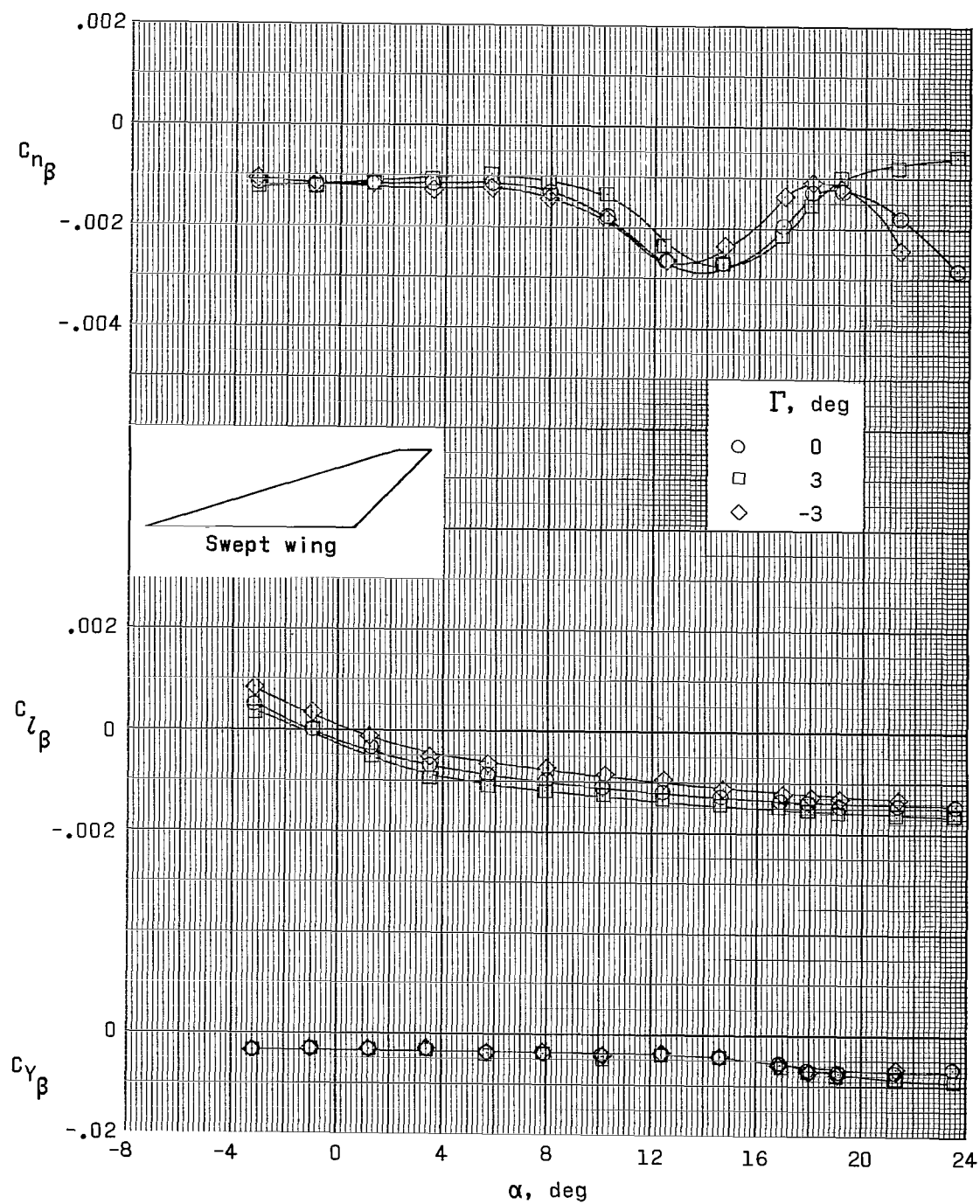
(d) $M = 4.63$.

Figure 5.- Concluded.



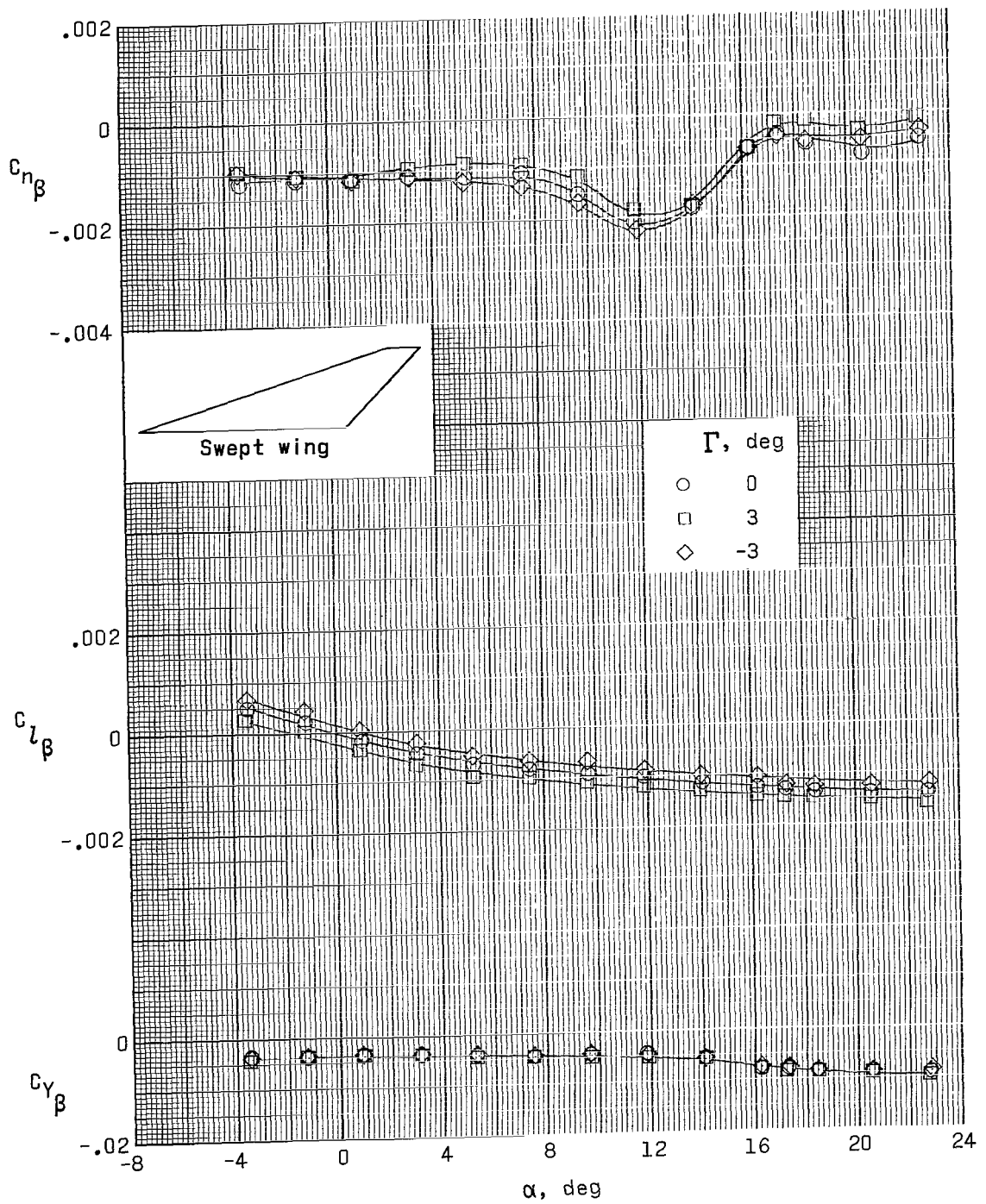
(a) $M = 1.80$.

Figure 6.- Effect of geometric dihedral on sideslip parameters for swept-wing configuration. Tail off.



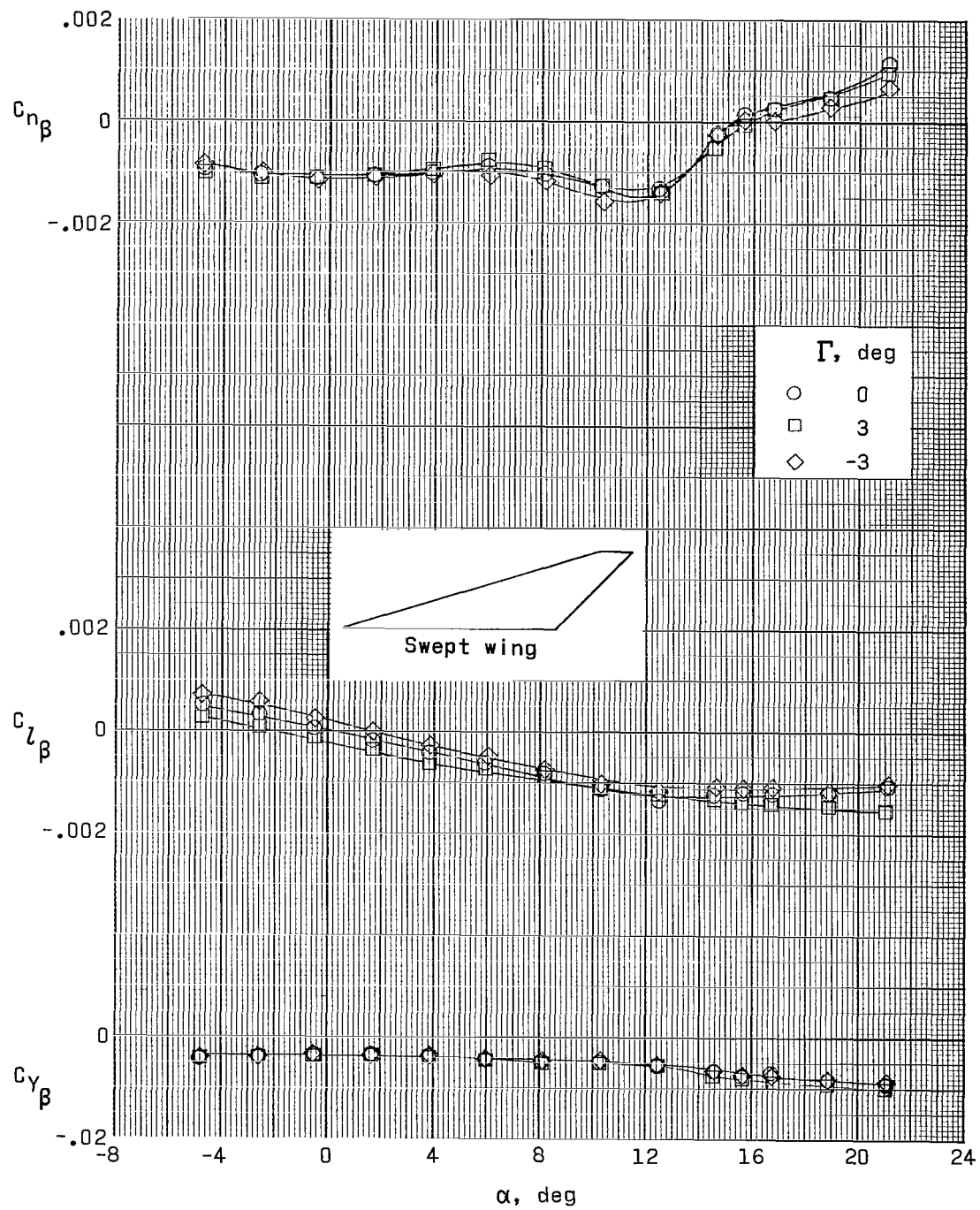
(b) $M = 2.16$.

Figure 6.- Continued.



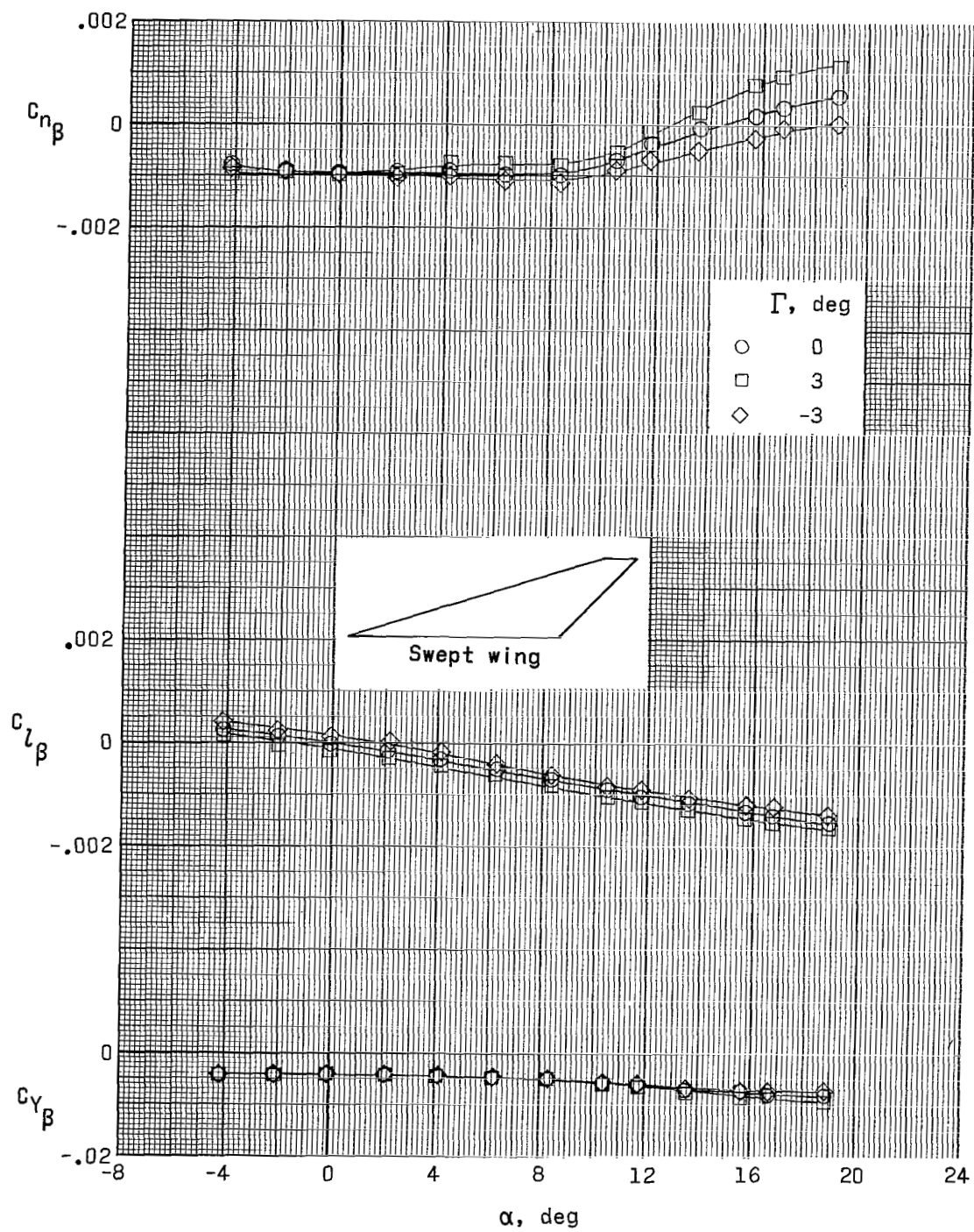
(c) $M = 2.50$.

Figure 6.- Continued.



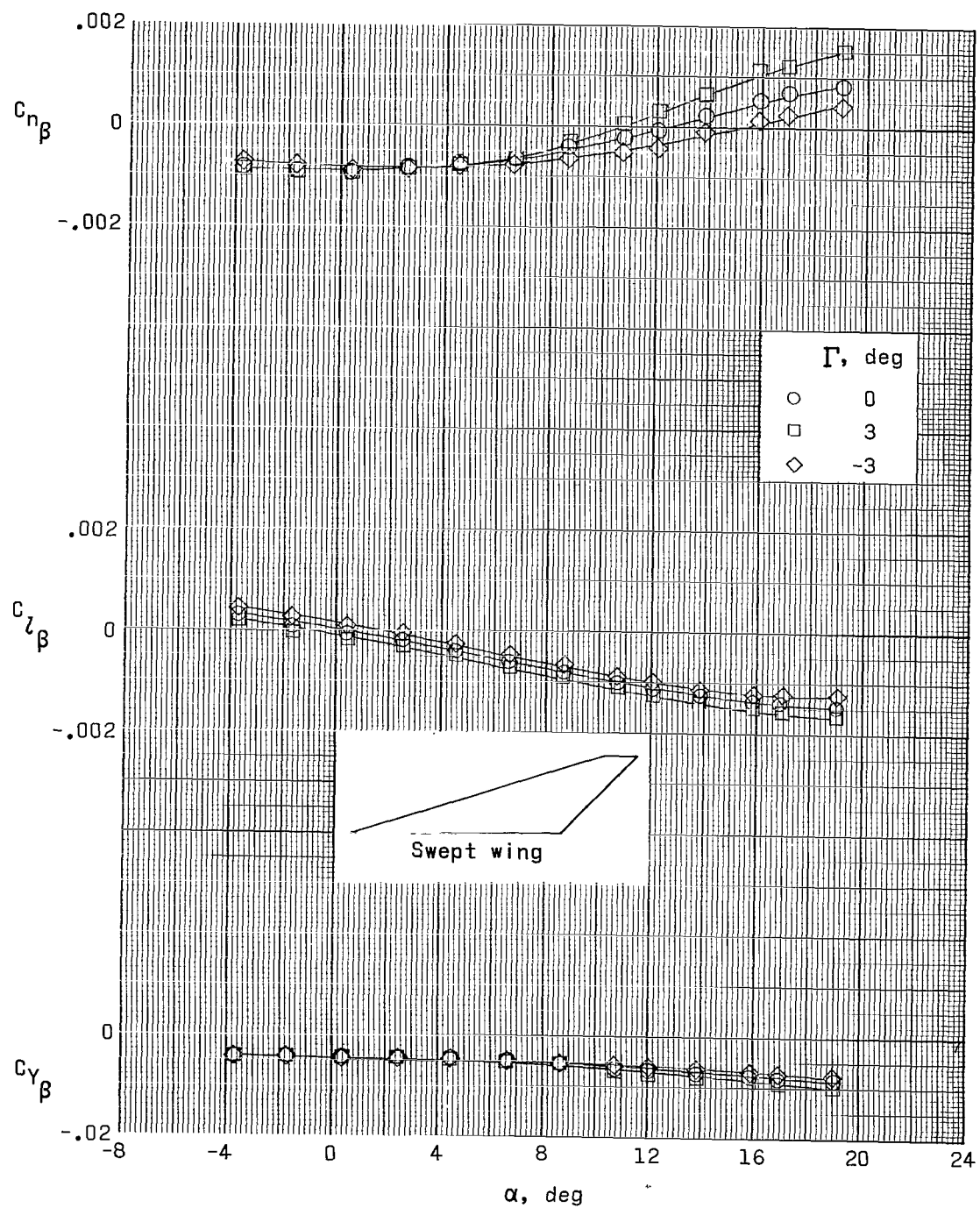
(d) $M = 2.86$.

Figure 6.- Continued.



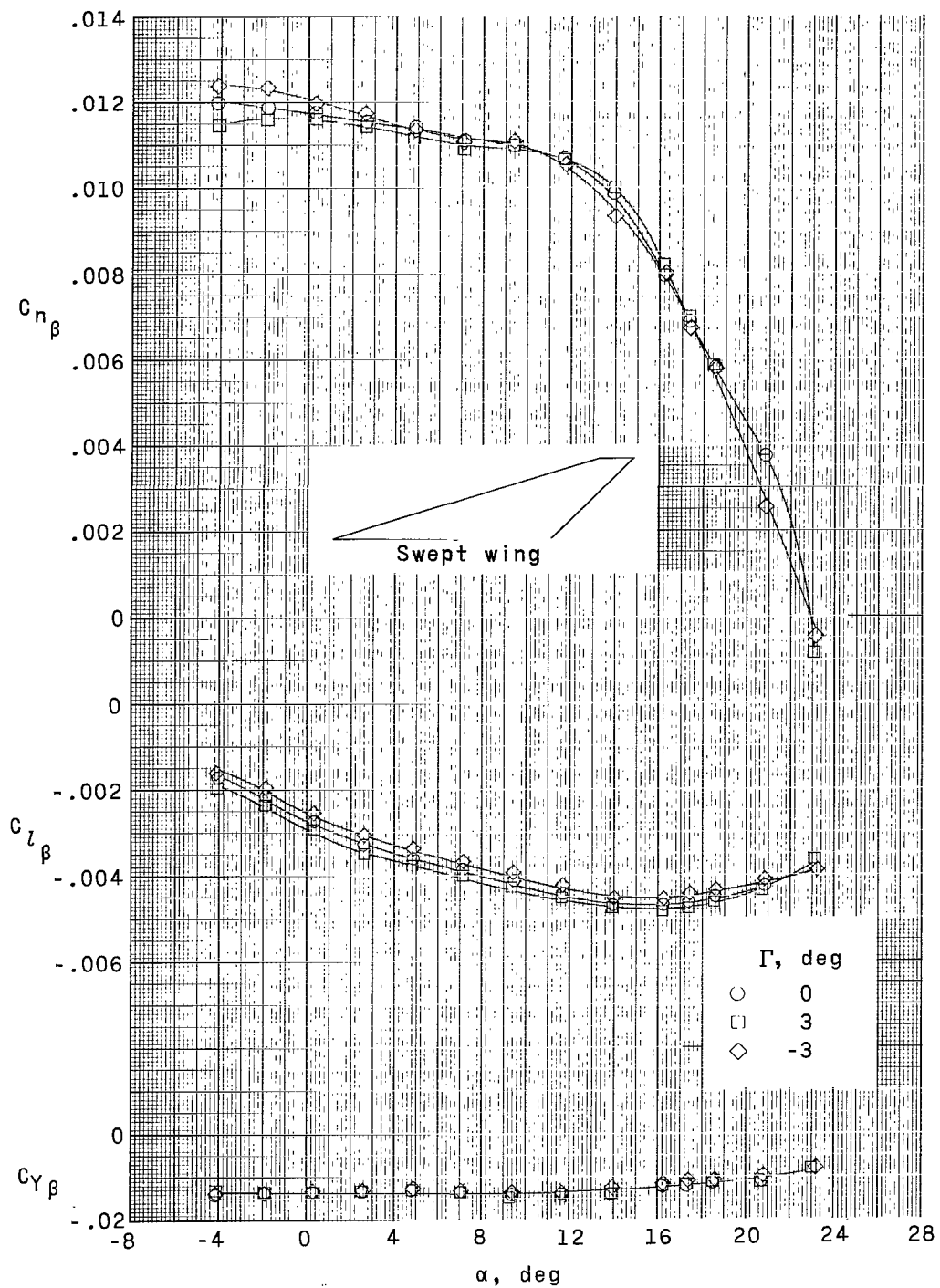
(e) $M = 3.95$.

Figure 6.- Continued.



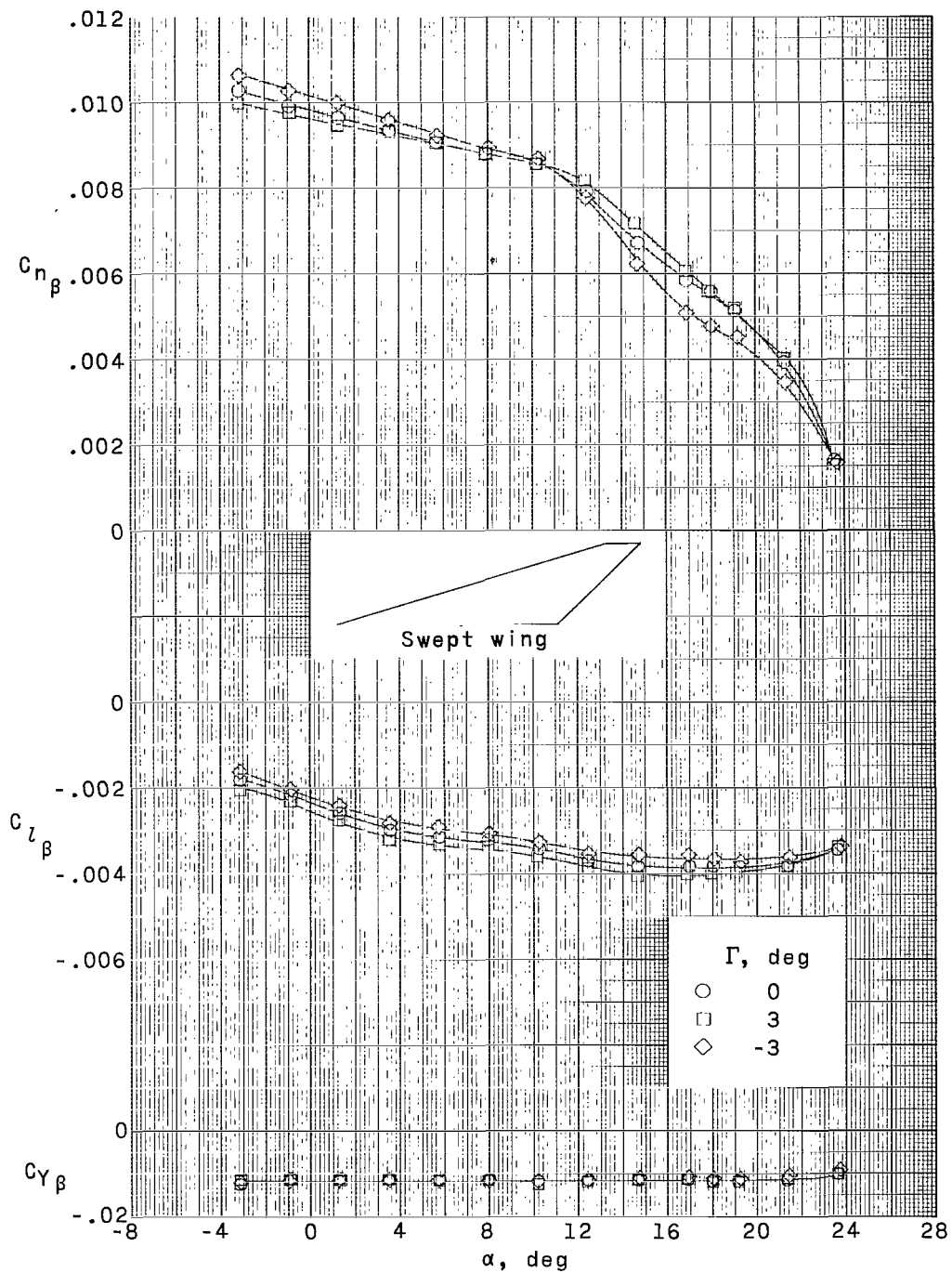
(f) $M = 4.63$.

Figure 6.- Concluded.



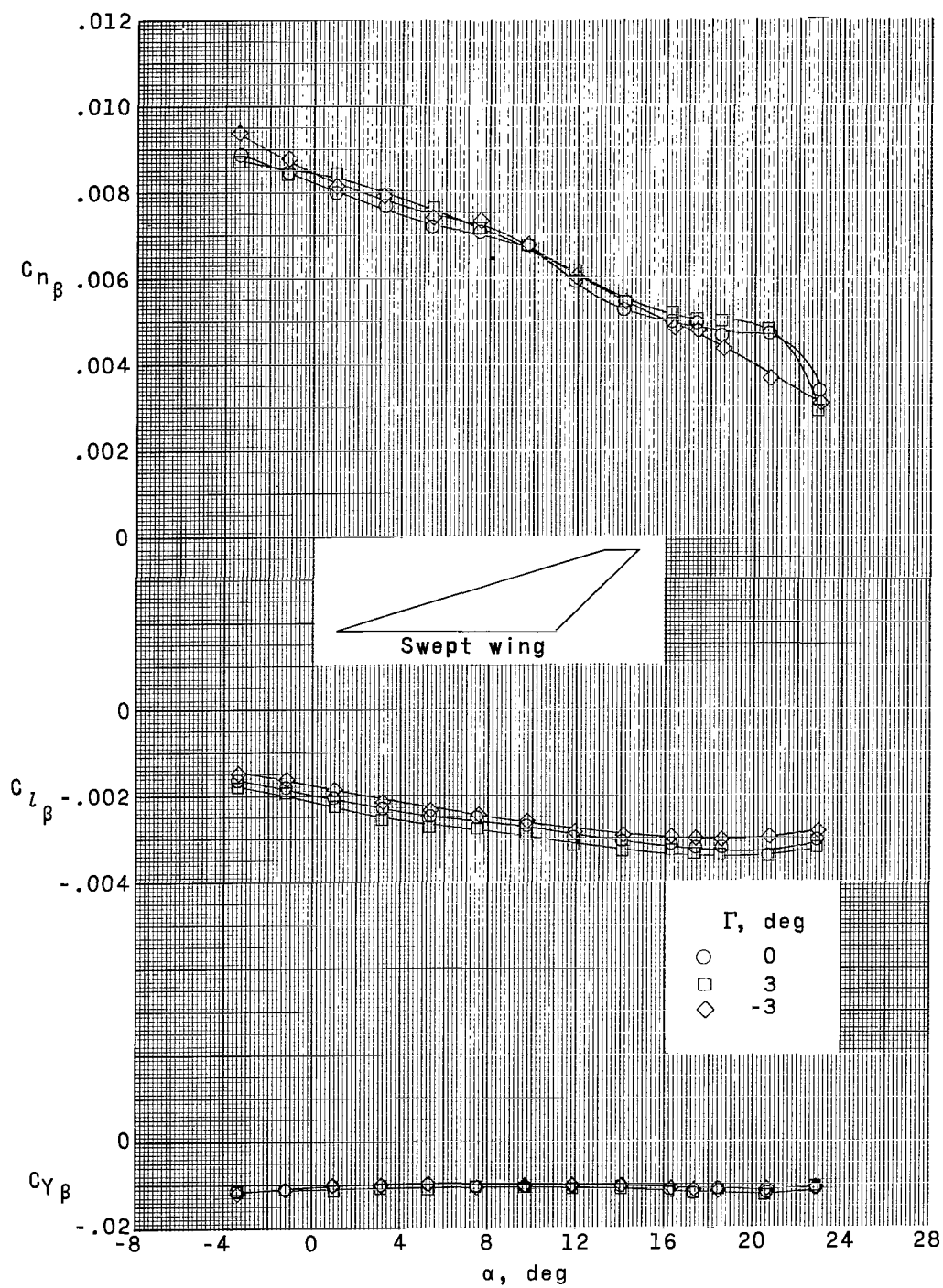
(a) $M = 1.80$.

Figure 7.- Effect of geometric dihedral on sideslip parameters for swept-wing configuration. Tail on.



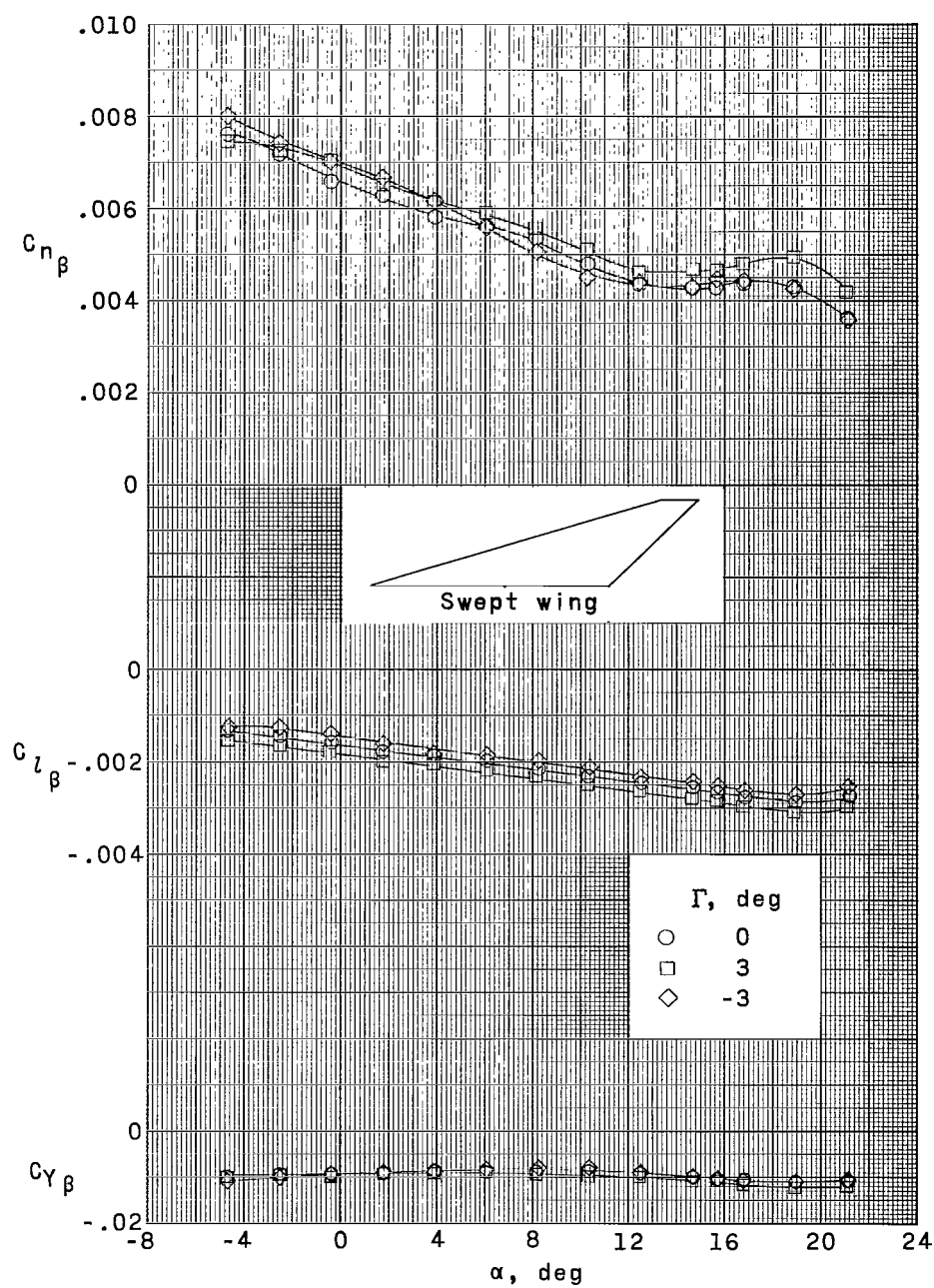
(b) $M = 2.16$.

Figure 7.- Continued.



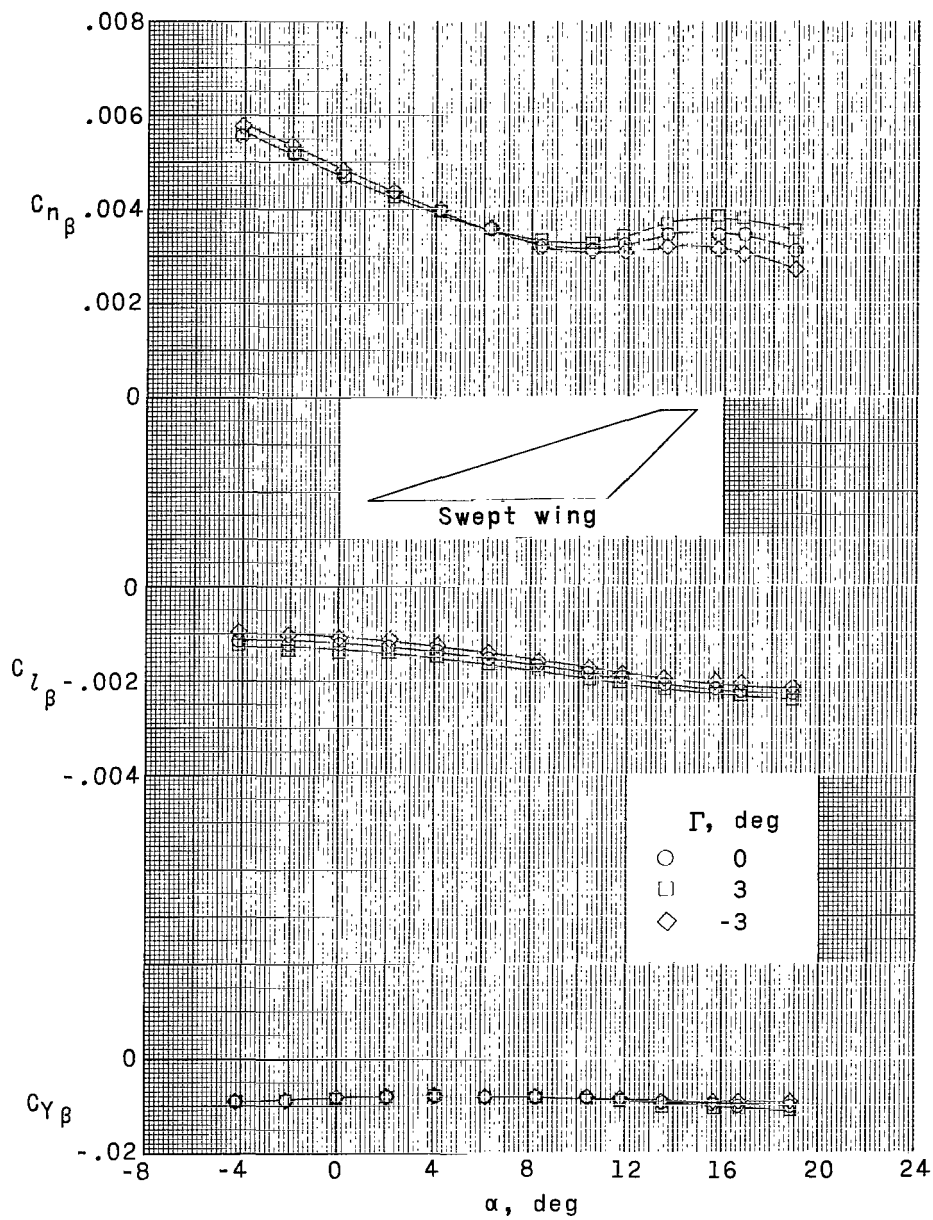
(c) $M = 2.50$.

Figure 7.- Continued.



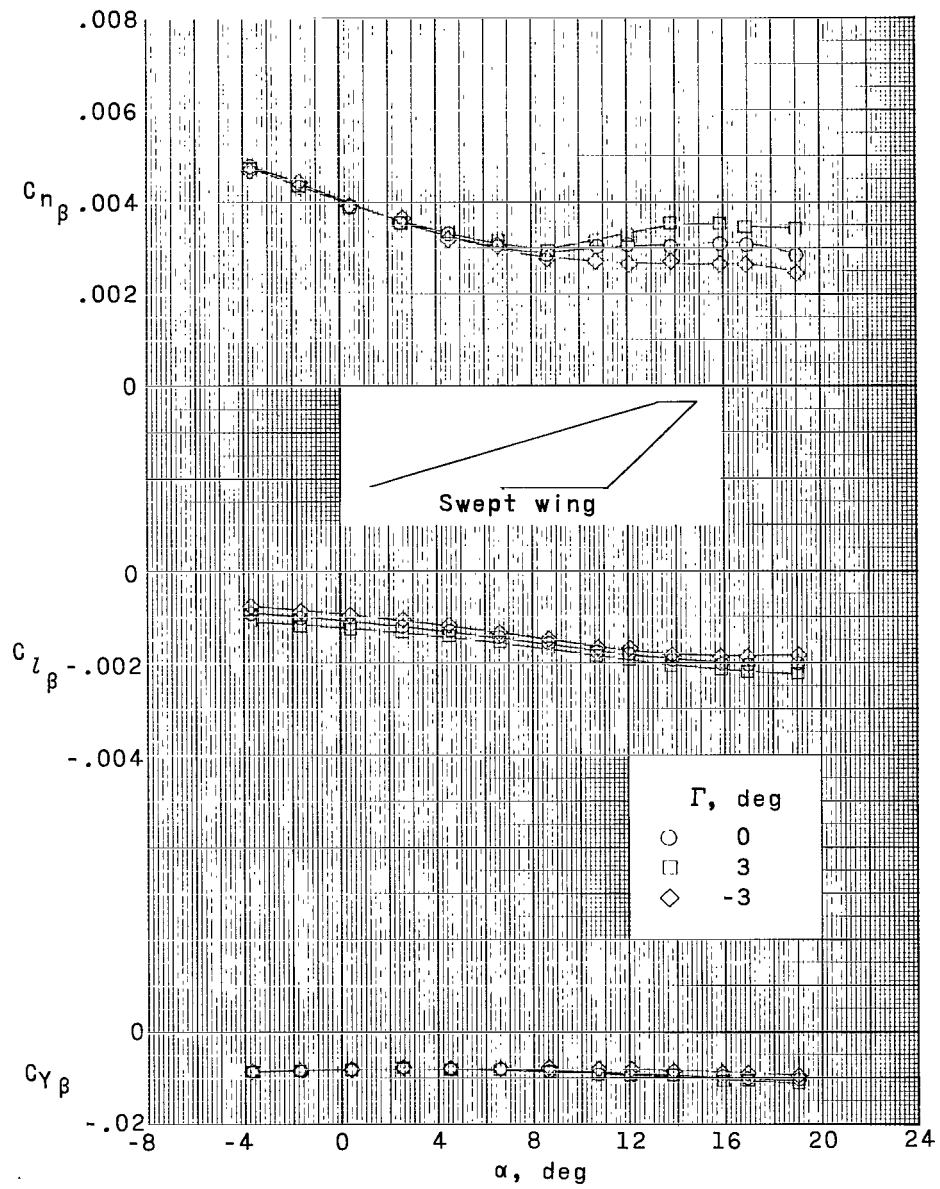
(d) $M = 2.86$.

Figure 7.- Continued.



(e) $M = 3.95$.

Figure 7.- Continued.



(f) $M = 4.63$.

Figure 7.- Concluded.

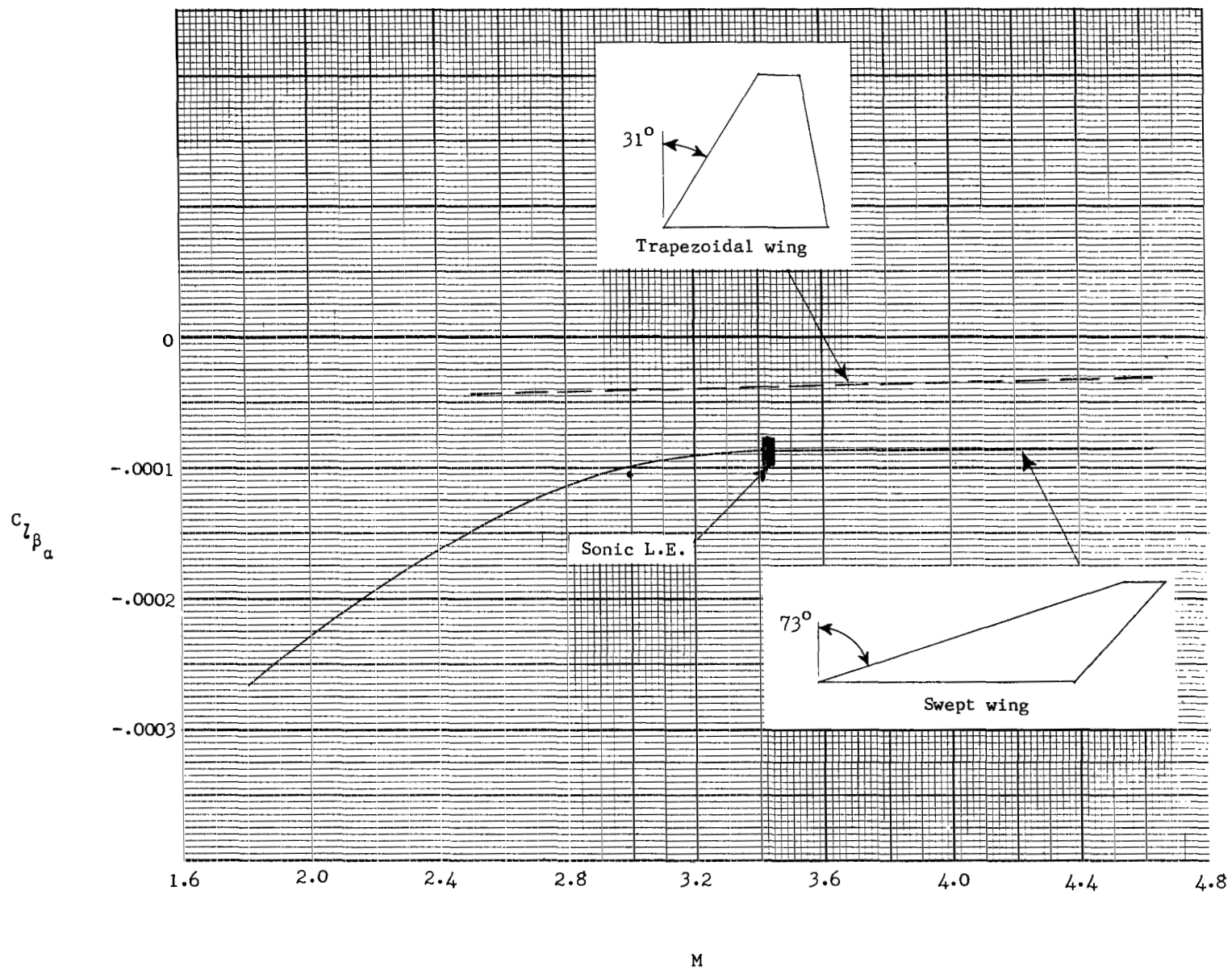
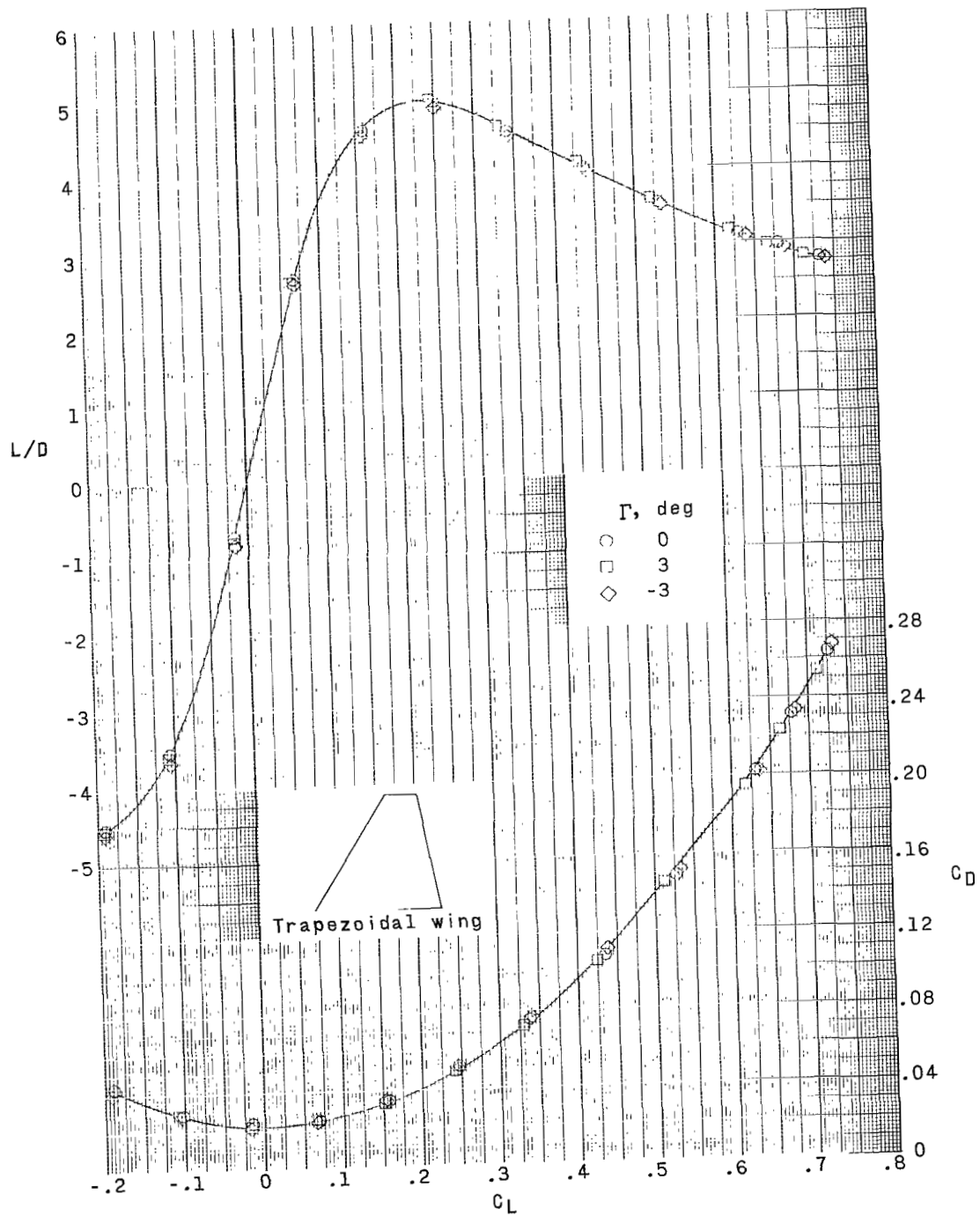
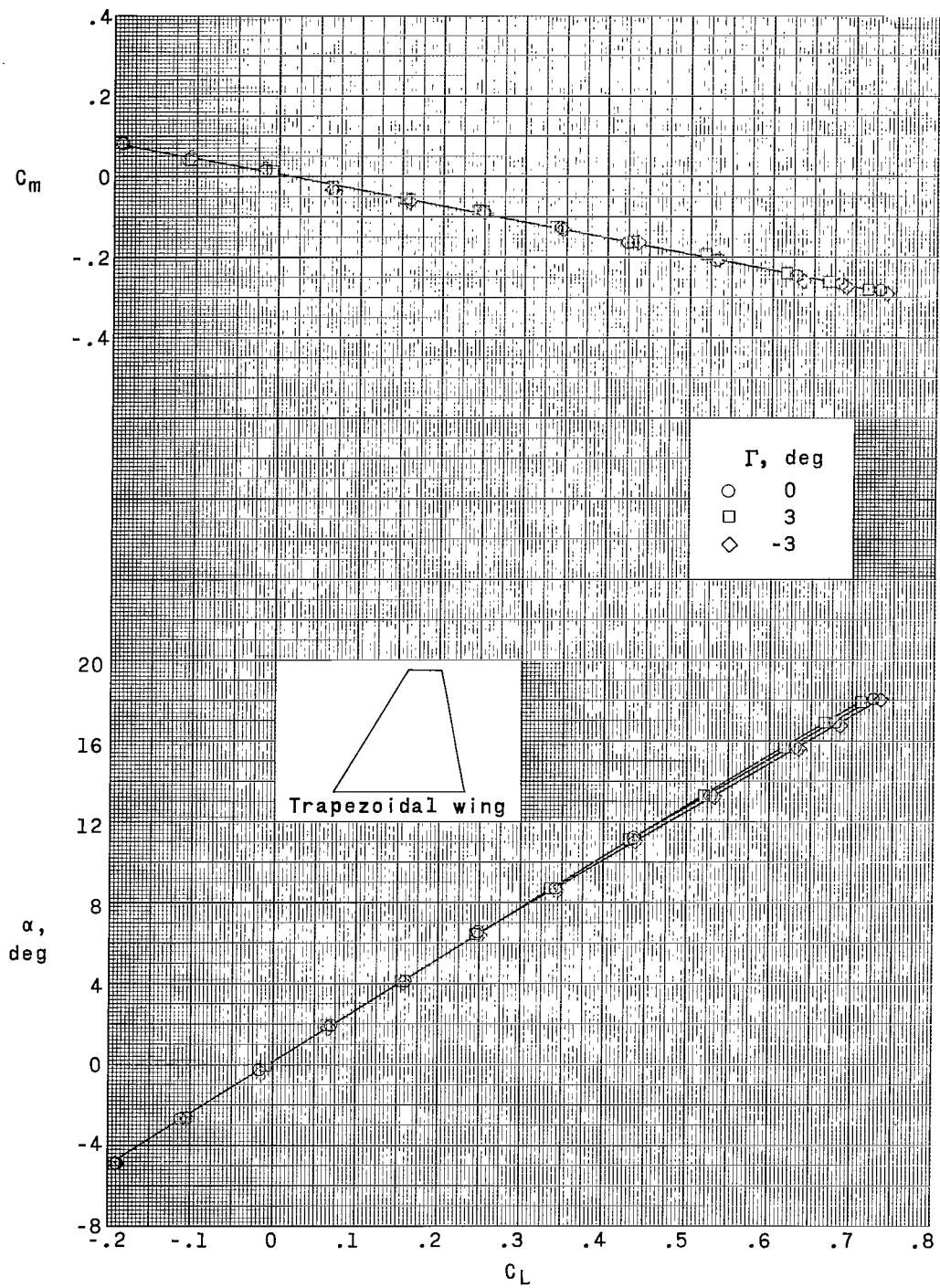


Figure 8.- Effect of wing planform and Mach number on the variation of the slope of the lateral-stability parameter with angle of attack.



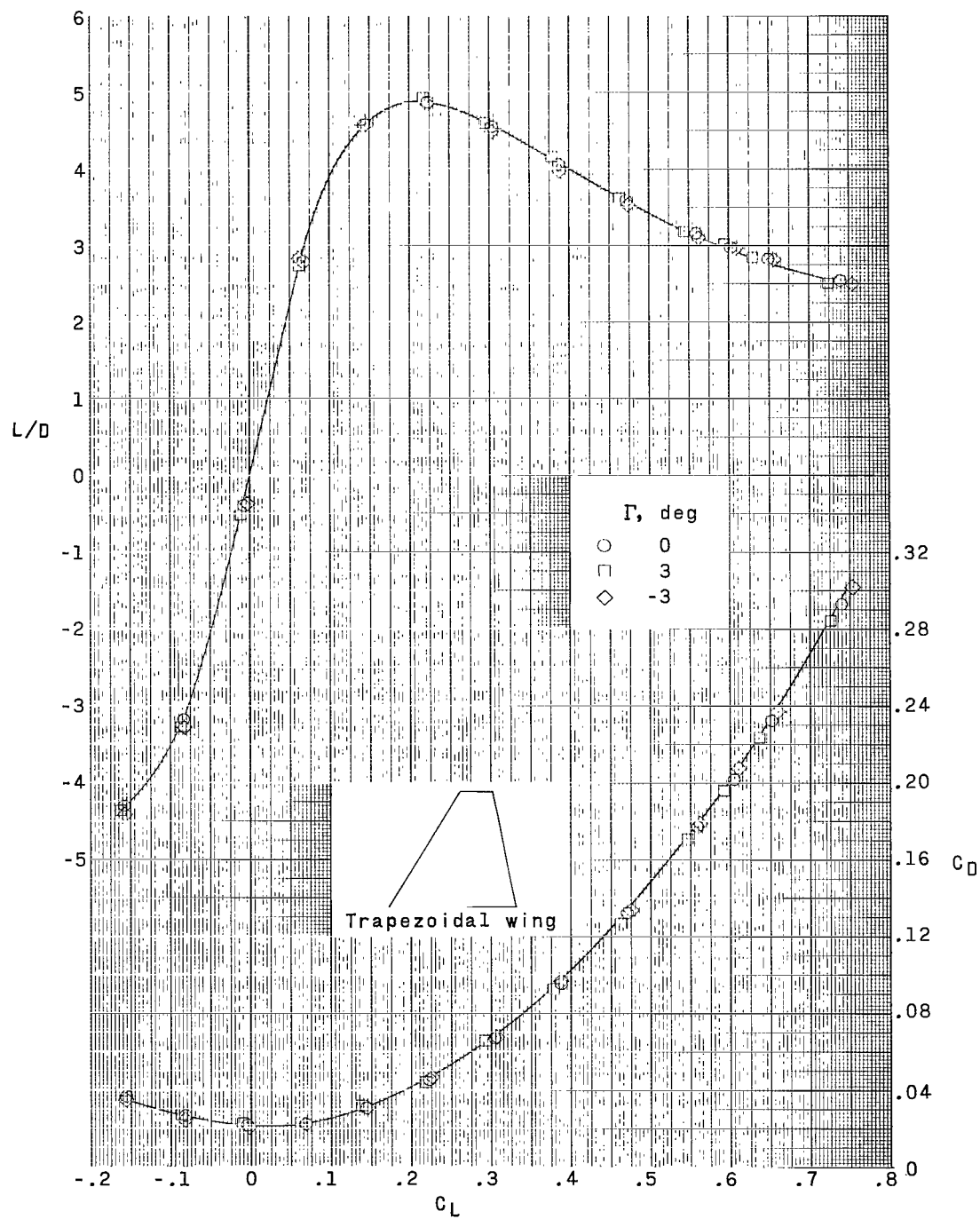
(a) $M = 2.50$.

Figure 9.- Effect of geometric dihedral on aerodynamic characteristics in pitch for trapezoidal-wing configuration. Tail on.



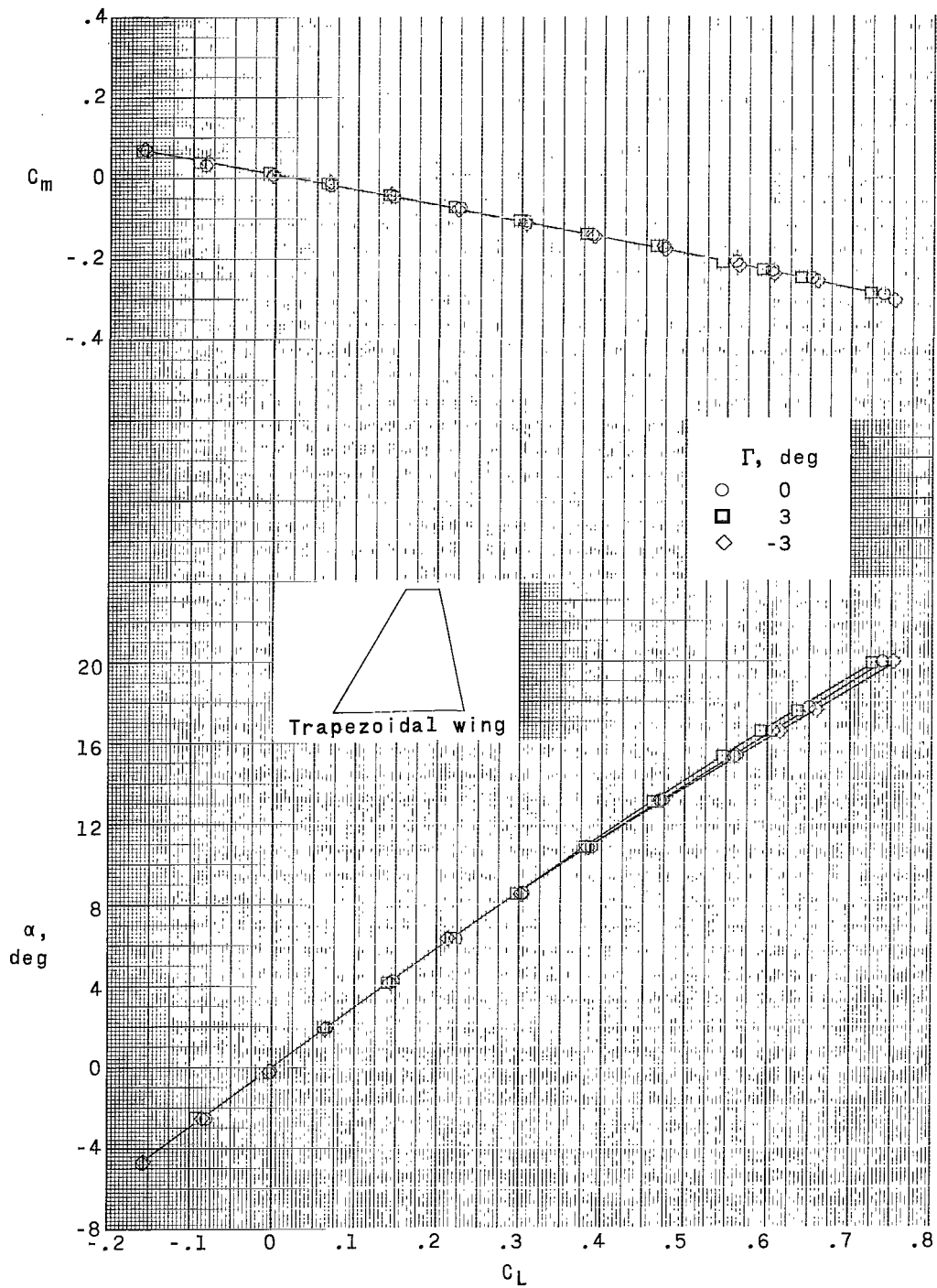
(a) Concluded.

Figure 9.- Continued.



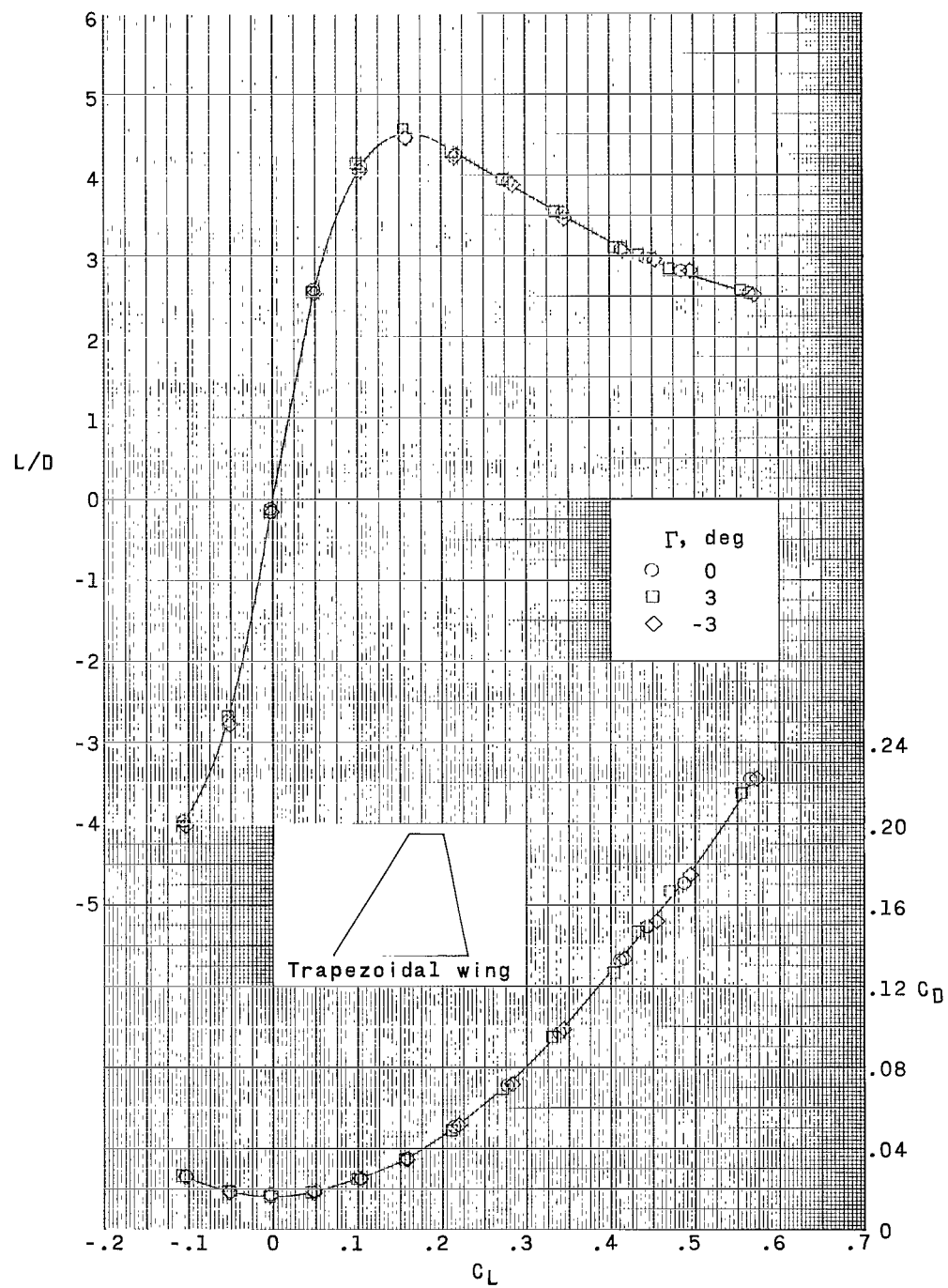
(b) $M = 2.86$.

Figure 9.- Continued.



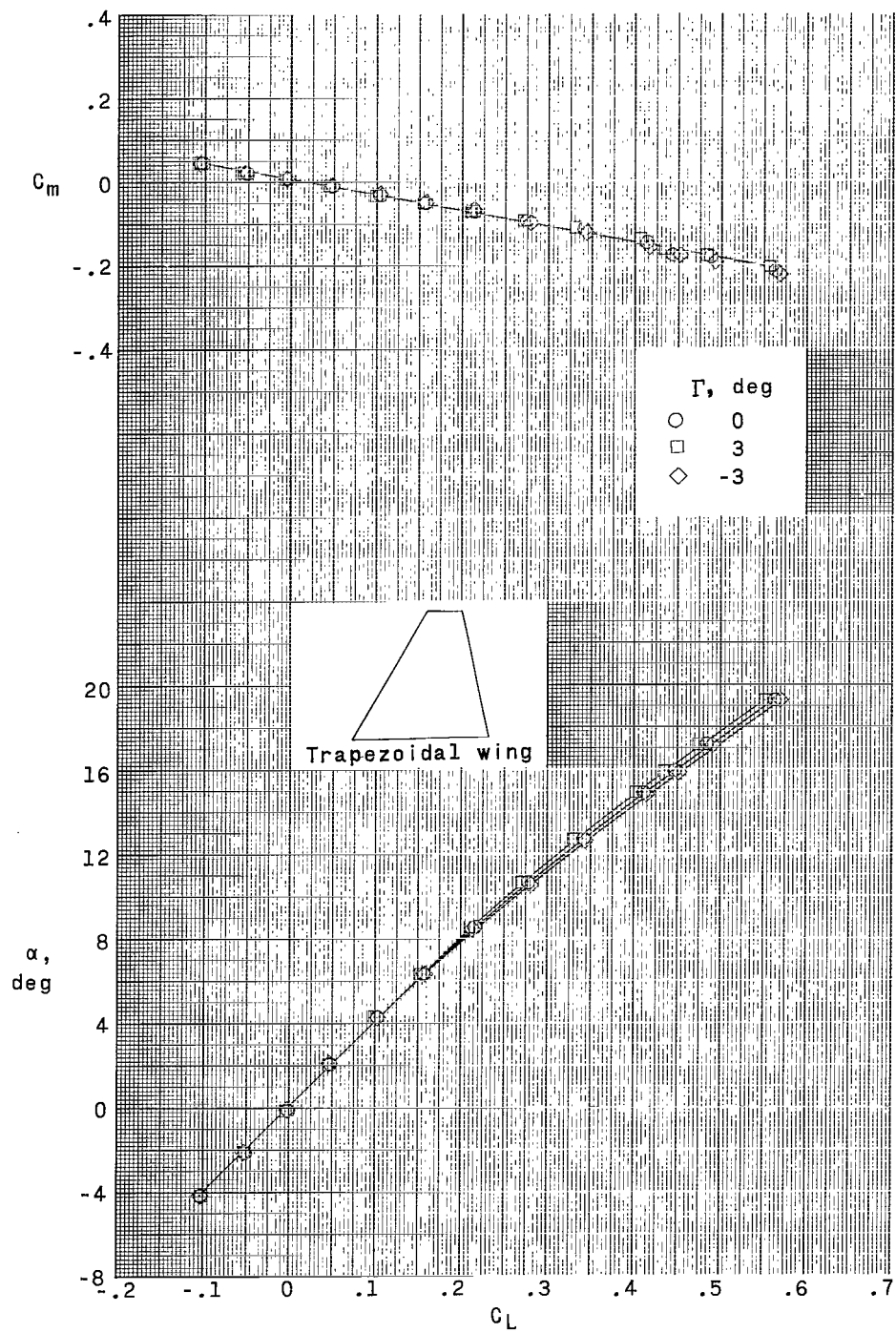
(b) Concluded.

Figure 9.- Continued.



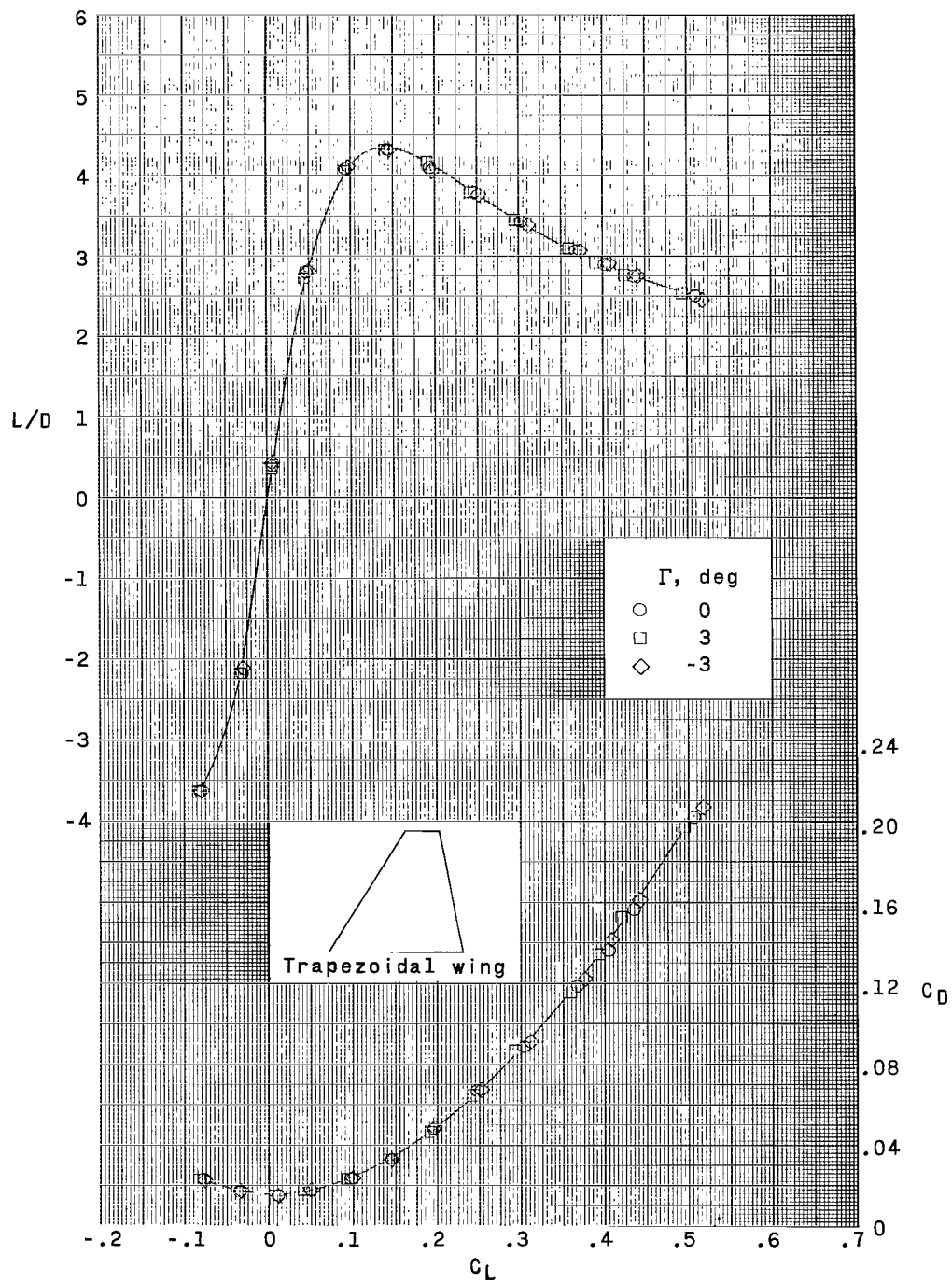
(c) $M = 3.95$.

Figure 9.- Continued.



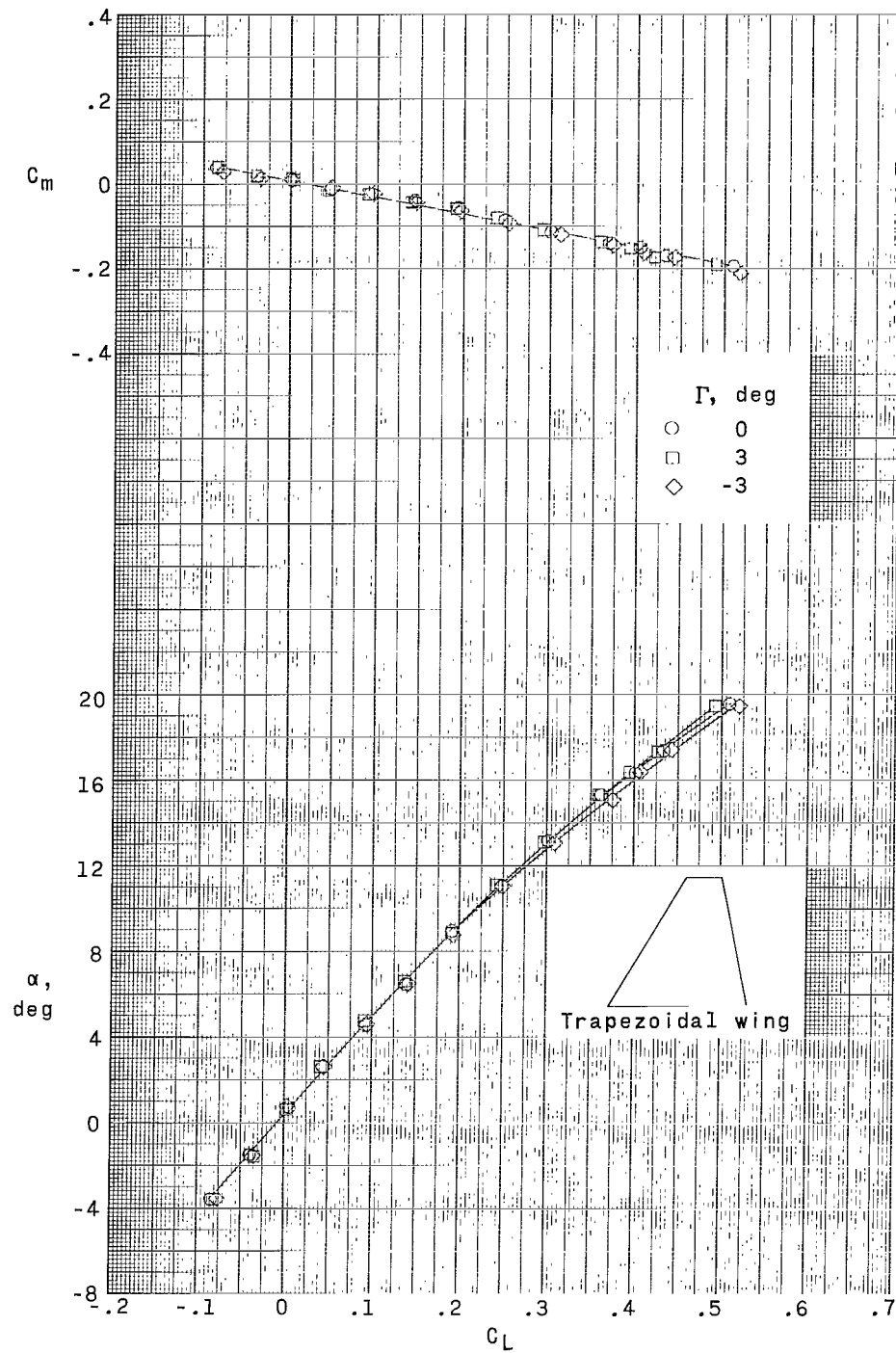
(c) Concluded.

Figure 9.- Continued.



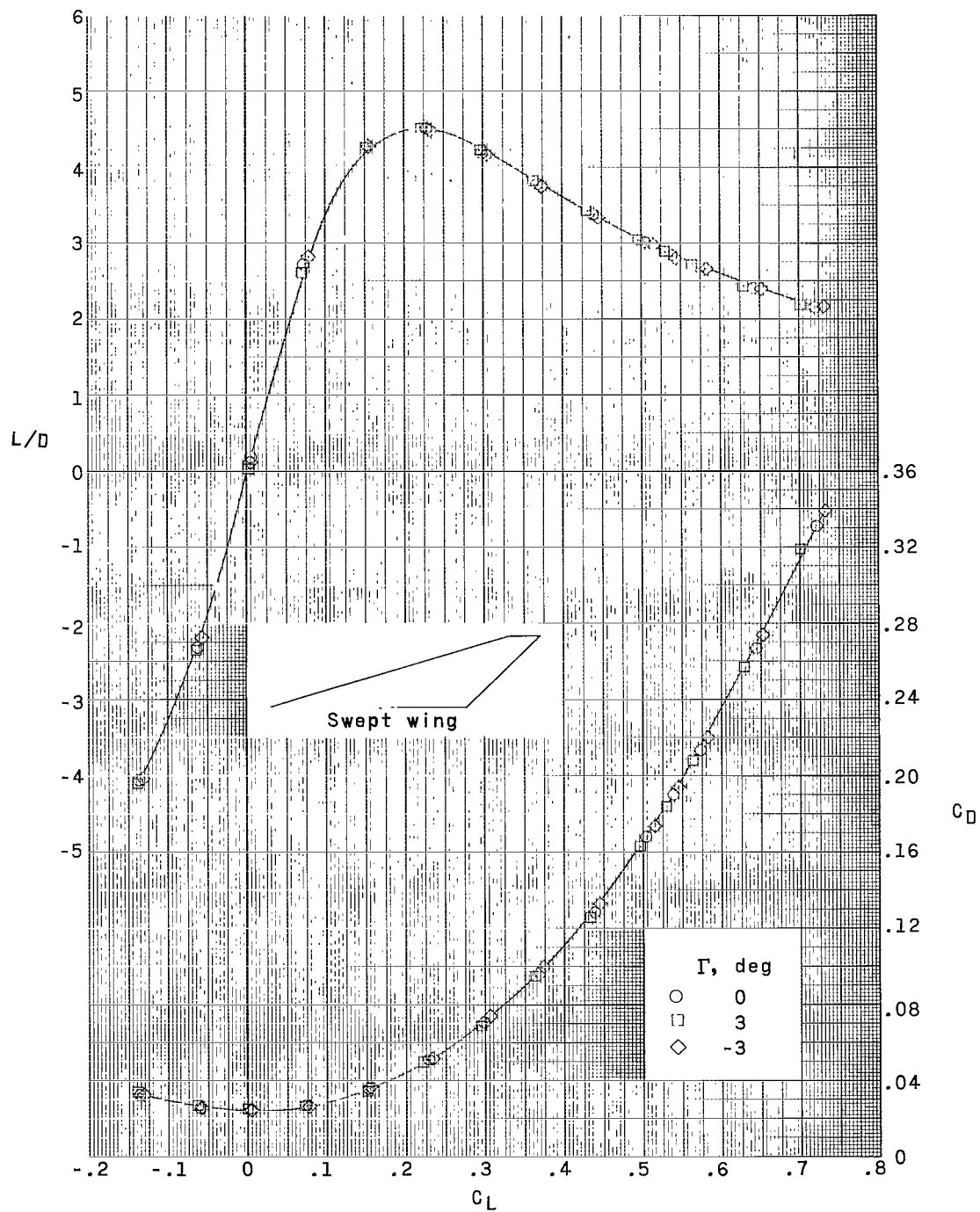
(d) $M = 4.63$.

Figure 9.- Continued.



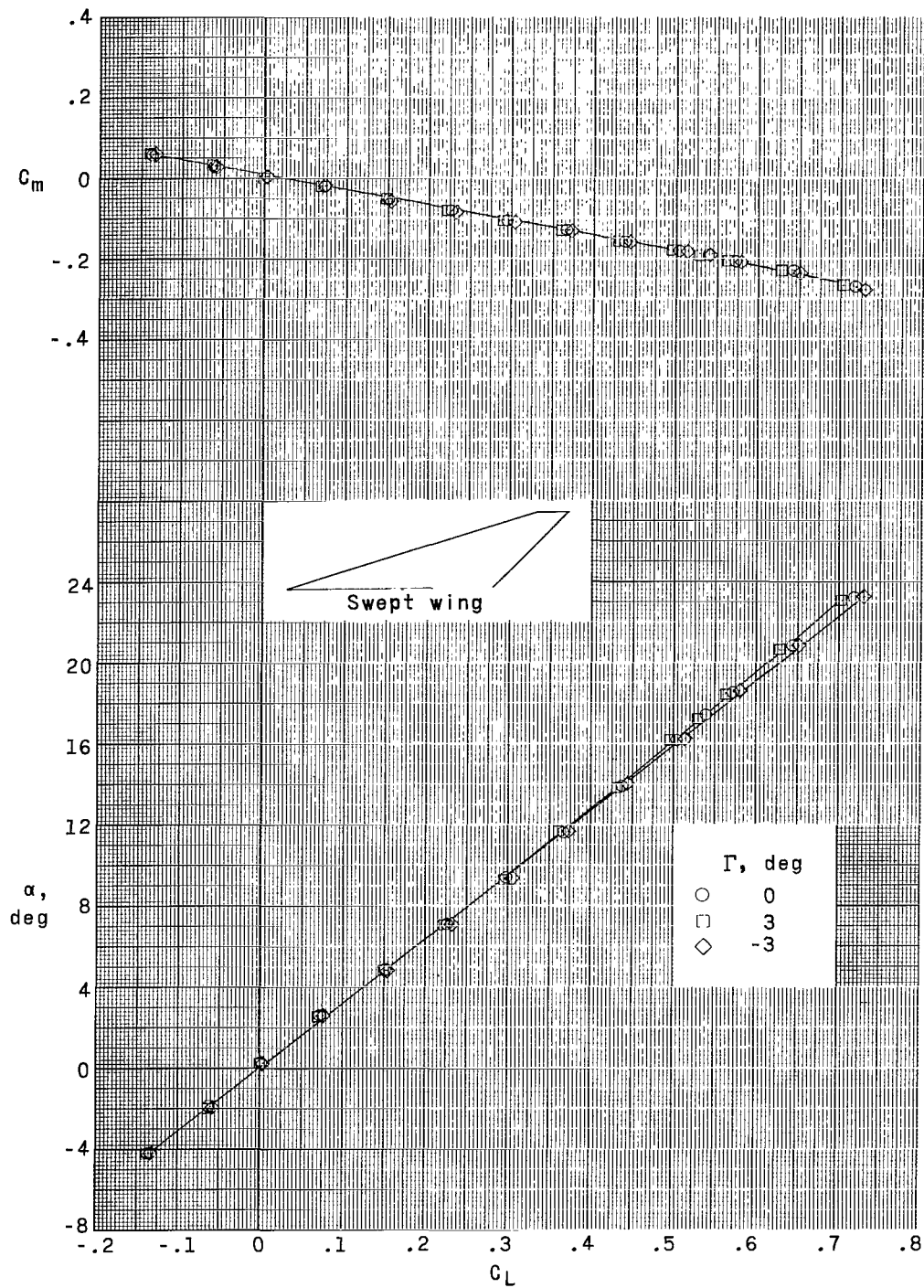
(d) Concluded.

Figure 9.- Concluded.



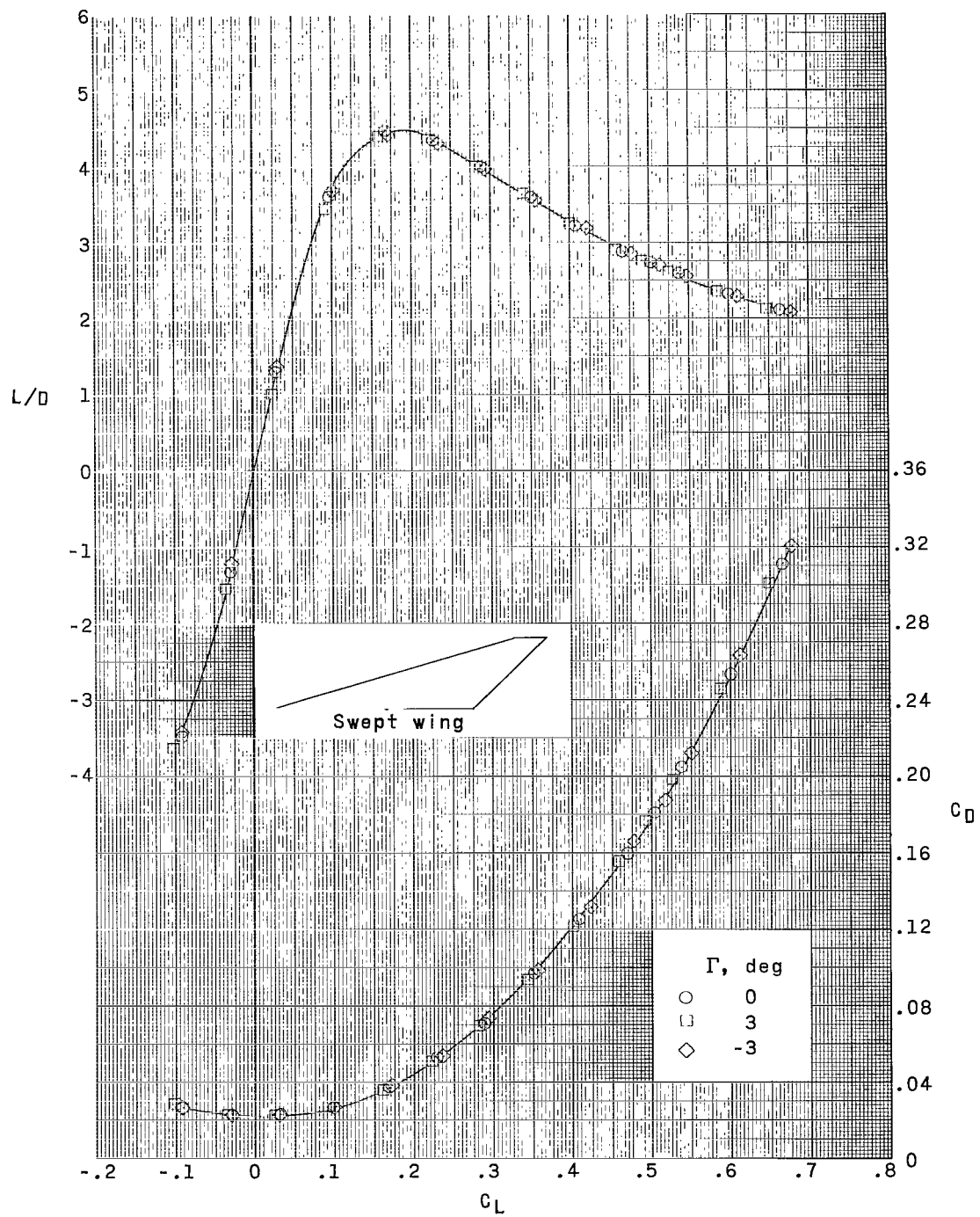
(a) $M = 1.80$.

Figure 10.- Effect of geometric dihedral on aerodynamic characteristics in pitch for swept-wing configuration. Tail on.



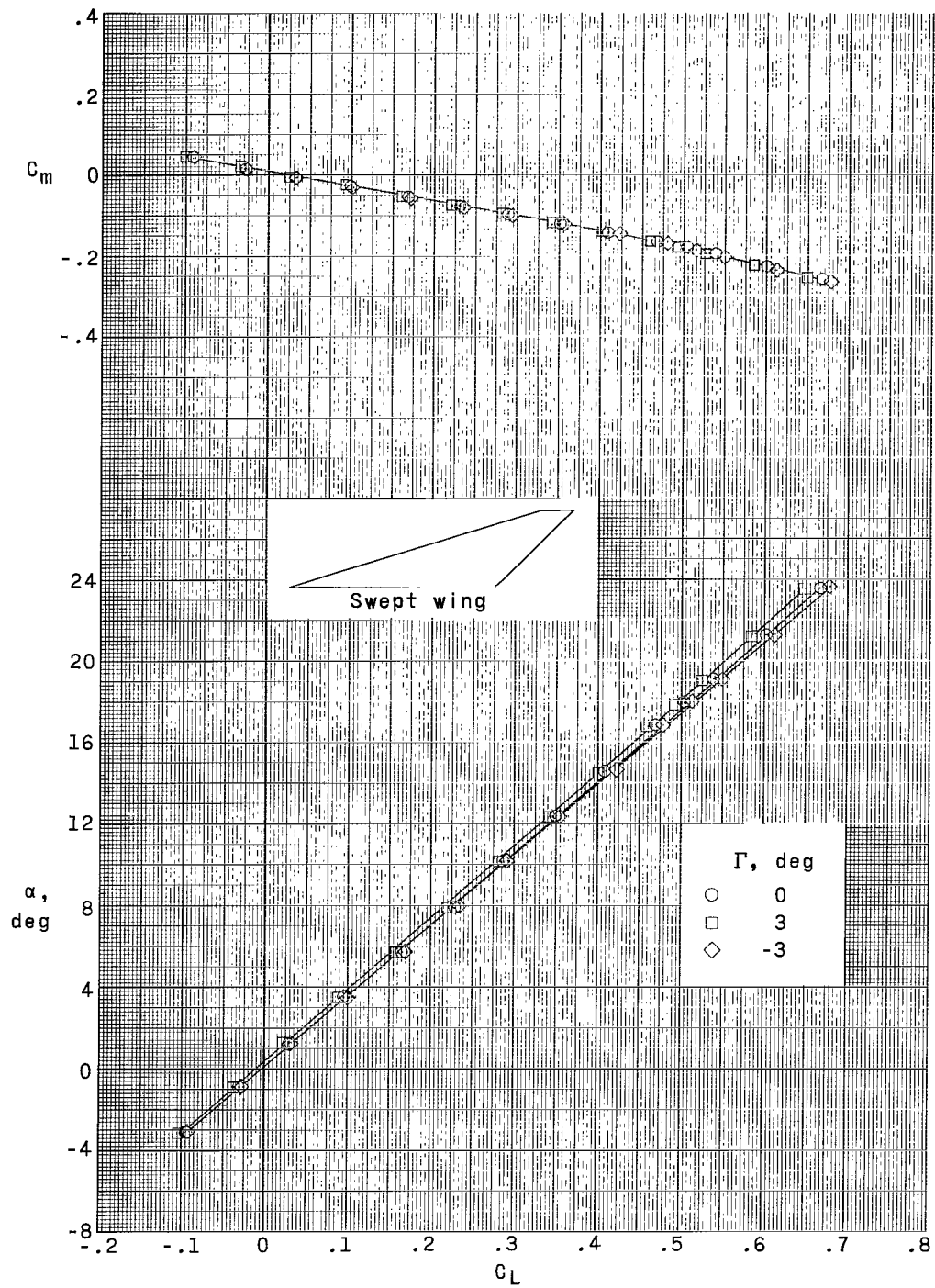
(a) Concluded.

Figure 10.- Continued.



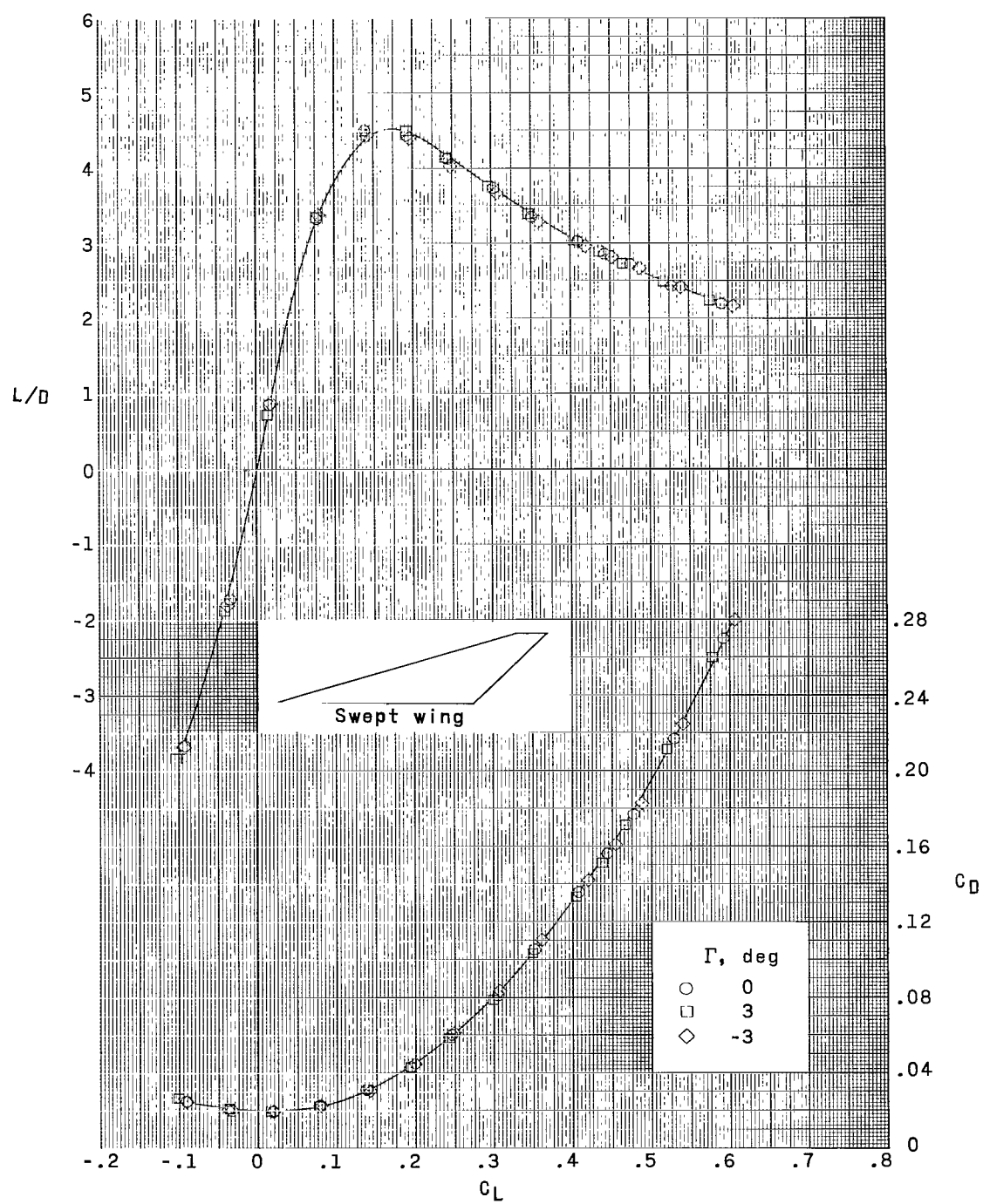
(b) $M = 2.16$.

Figure 10.- Continued.



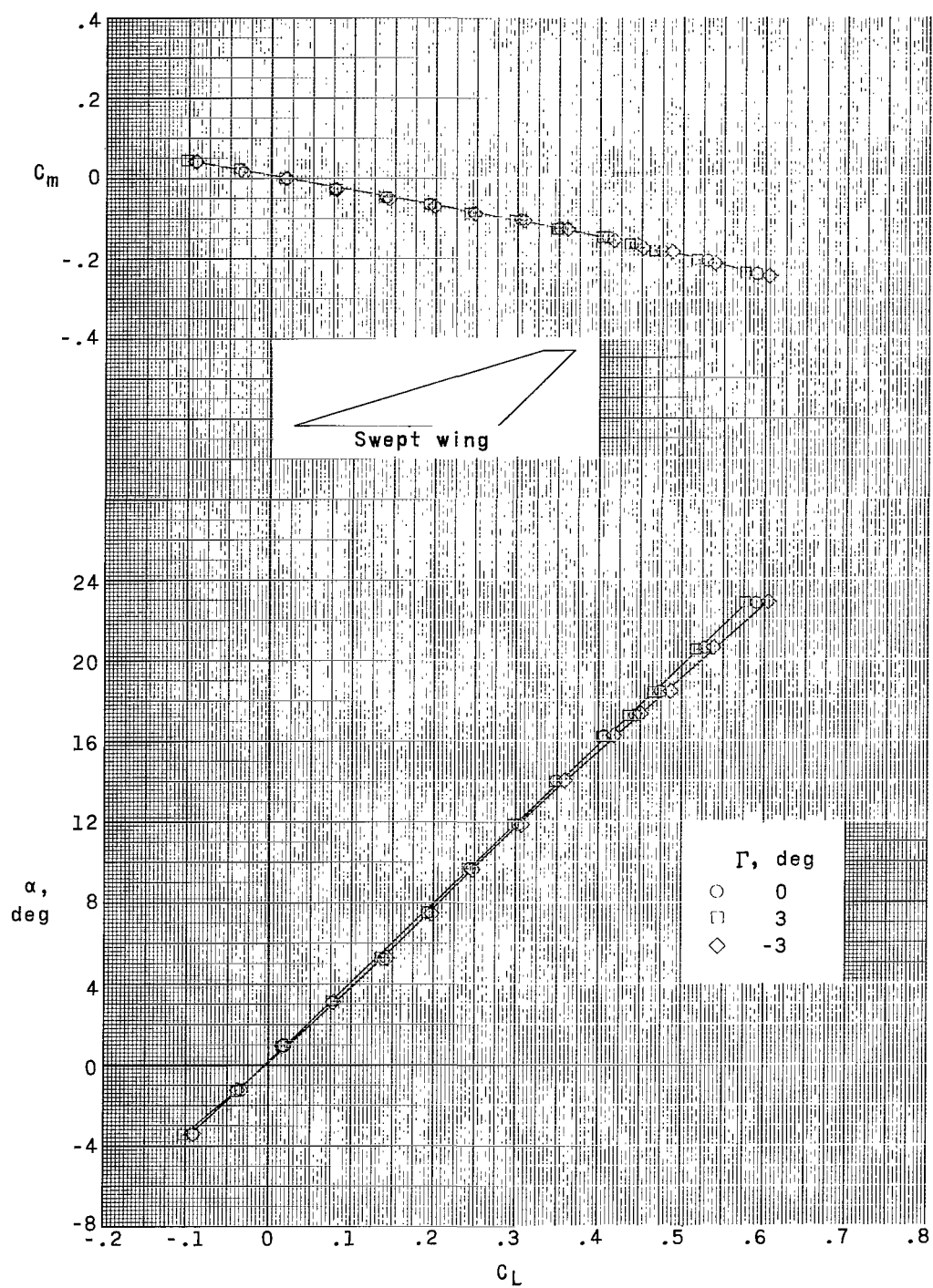
(b) Concluded.

Figure 10.- Continued.



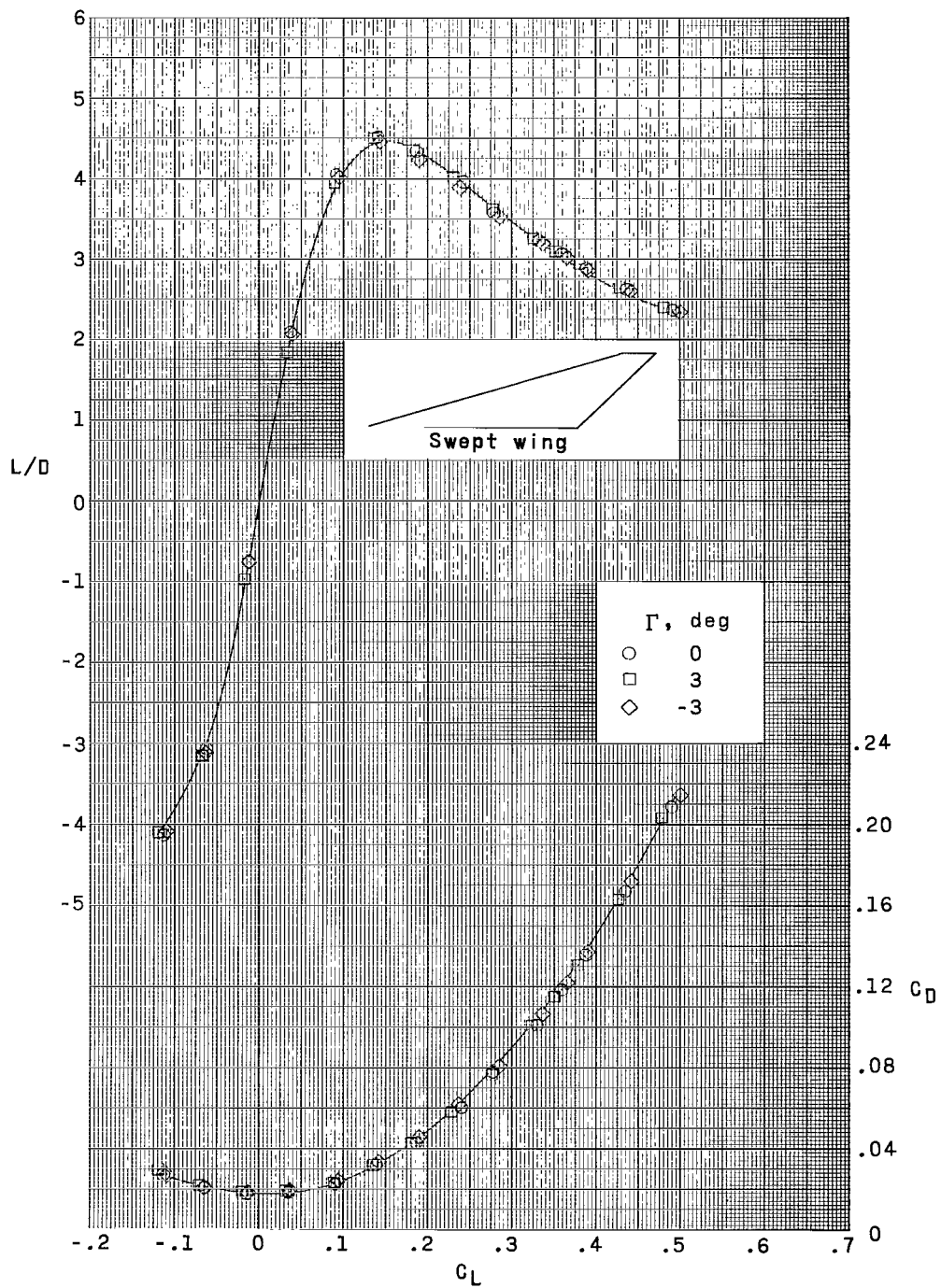
(c) $M = 2.50$.

Figure 10.- Continued.



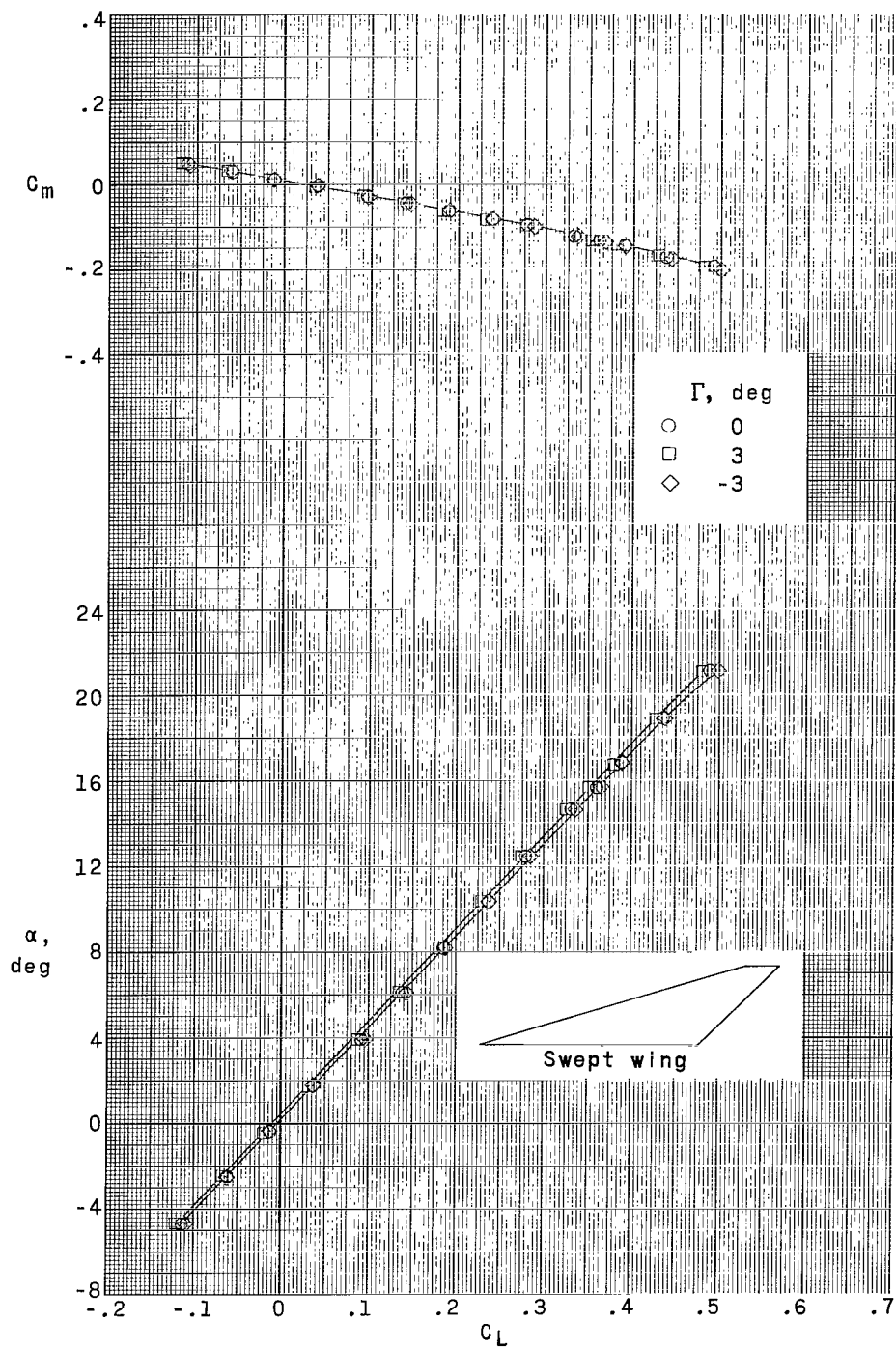
(c) Concluded.

Figure 10.- Continued.



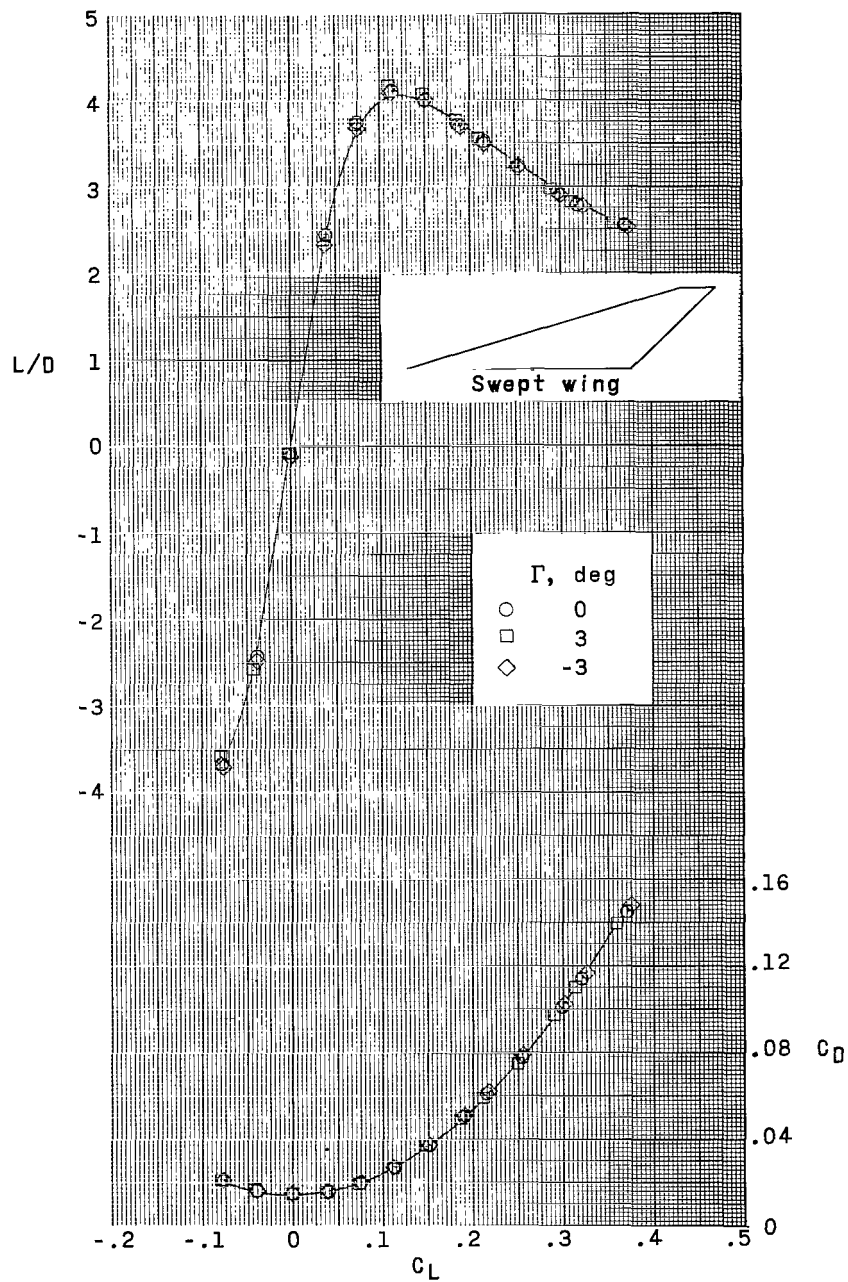
(d) $M = 2.86$.

Figure 10.- Continued.



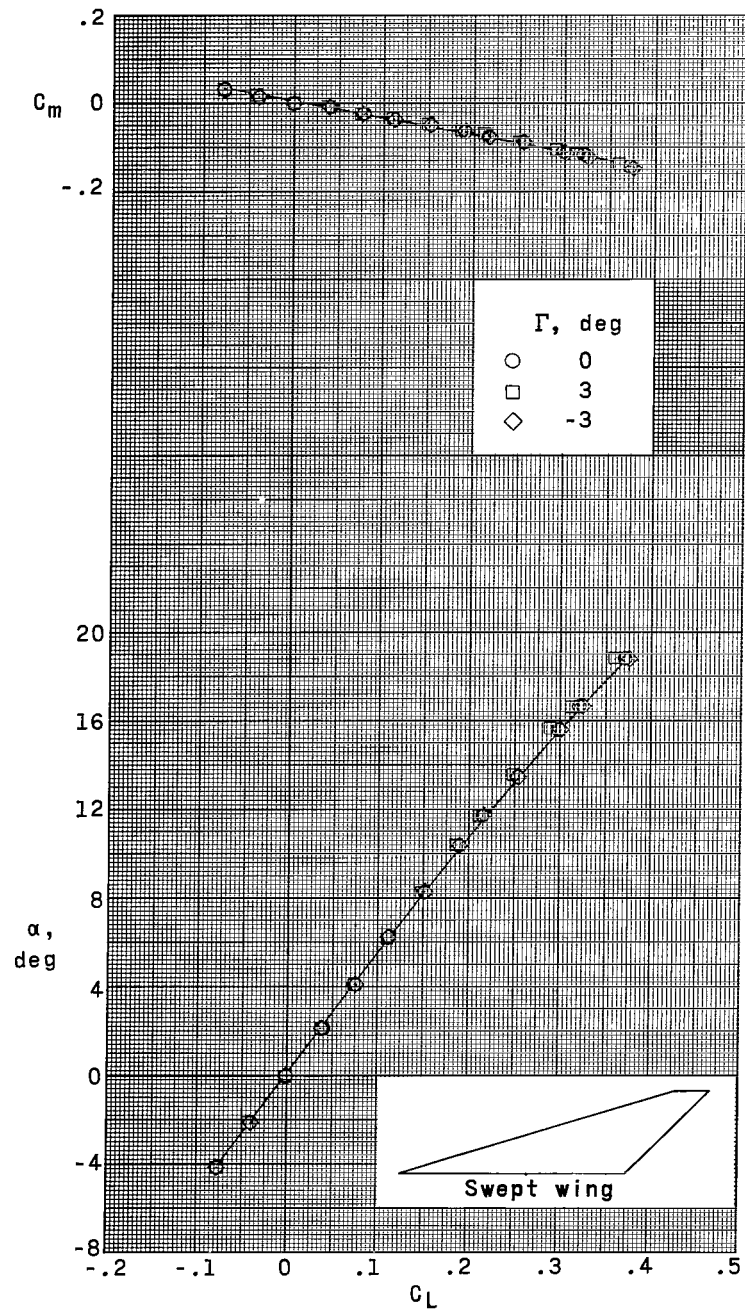
(d) Concluded.

Figure 10.- Continued.



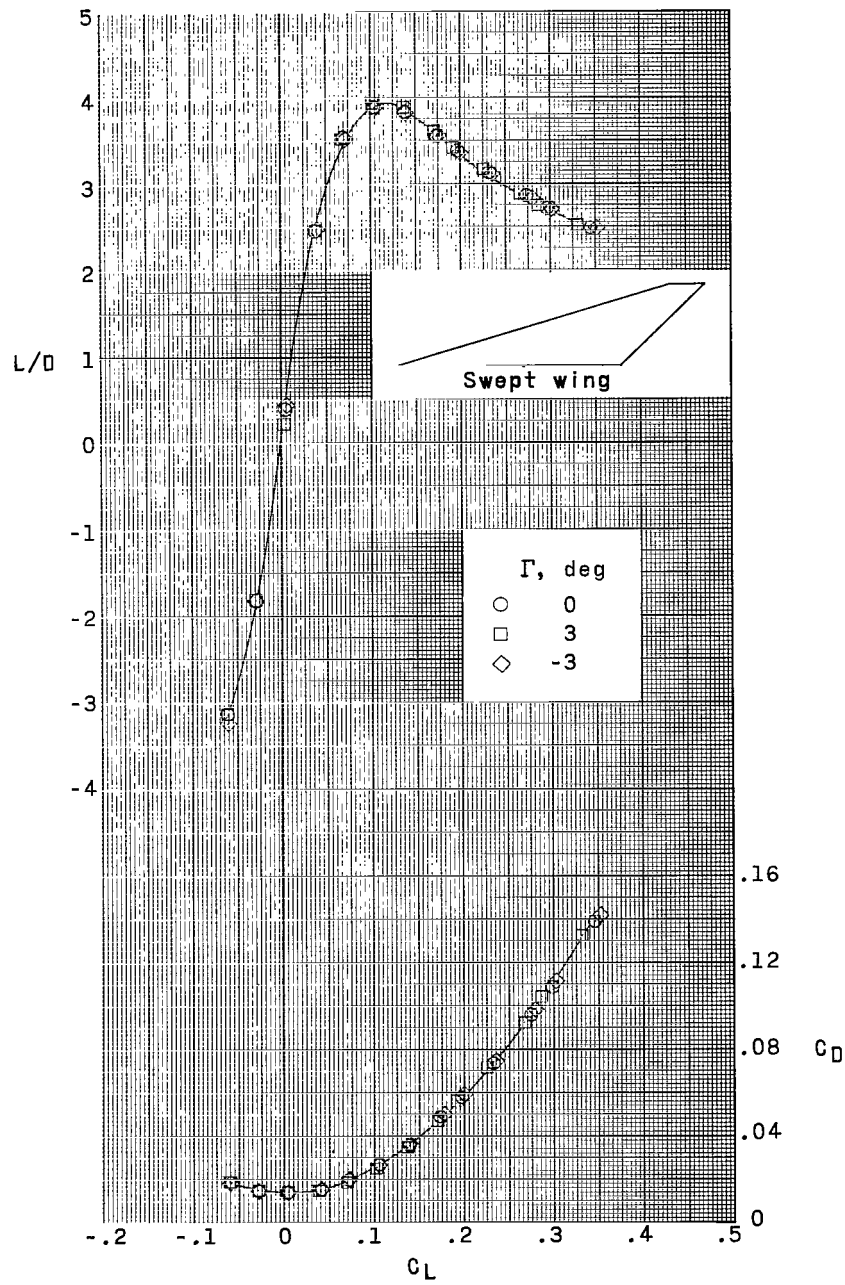
(e) $M = 3.95$.

Figure 10.- Continued.



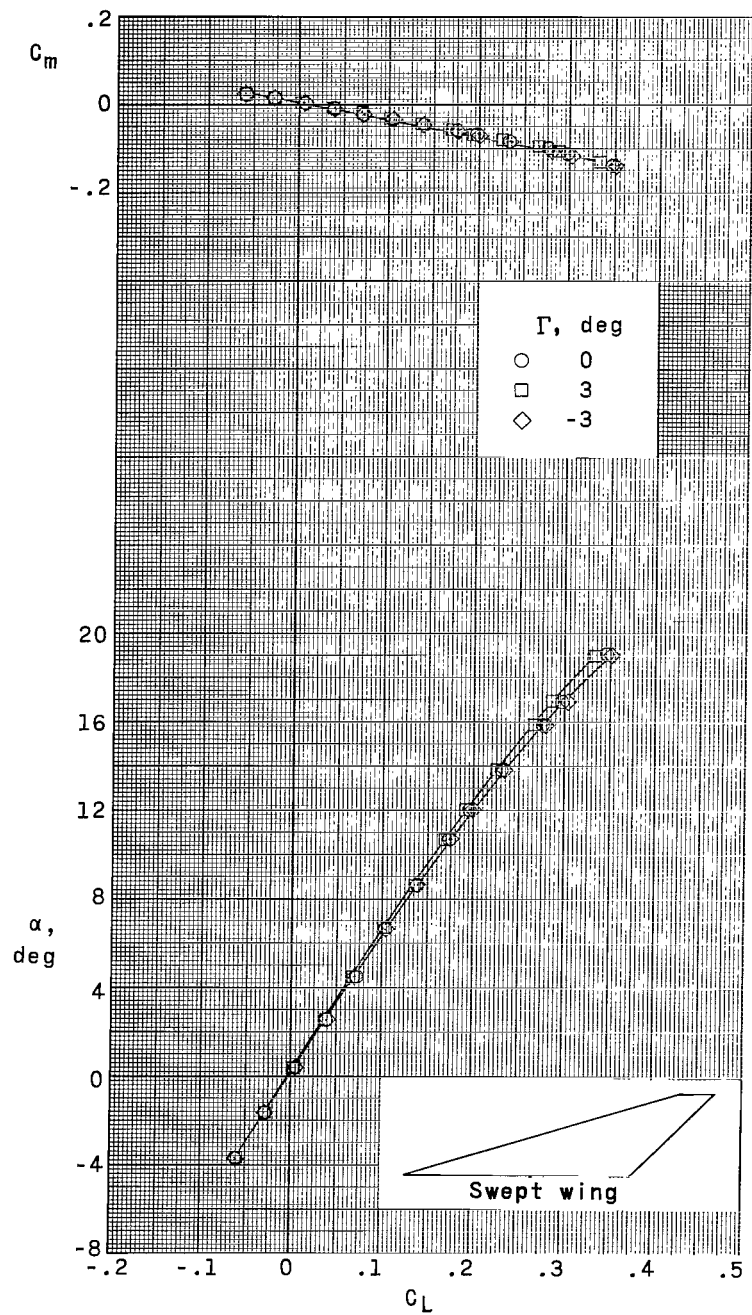
(e) Concluded.

Figure 10.- Continued.



(f) $M = 4.63$.

Figure 10.- Continued.



(f) Concluded.

Figure 10.- Concluded.

2/22/85
85

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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